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33-I/111

NON-COHERENT GROUND-BASED
MOVING TARGET INDICATOR

Report Number R-33
Copy 118 of 125 copies

January 1953

Prepared by:

P Gerald Kruger

Norman Knable

Robert W. Jackman

CONTROL SYSTEMS LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS
Contract DA-11-022-ORD-721

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DESIGN FEATURES AND TACTICAL USE OF A NON-COHERENT GROUND-BASED MOVING-TARGET INDICATOR

Report Number R-33

January 1953

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Contract DA-11-022-ORD-721

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ABSTRACT

This report describes a non-coherent, ground-based moving-target indicator, designed to detect enemy troops, tanks, and trucks near the front lines where the velocity of such targets is likely to be between two and ten m.p.h. Some simple theory is given and reference is made to other more complete descriptions of the theory. Details of the equipment are given in the appendices. Some results of tests of the equipment are included.

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INTRODUCTION

This report describes a ground-based moving-target indicator which is similar to and an extension of the APS/58 airborne set developed at the Control Systems Laboratory. The basic theory of this non-coherent system is to be found in two reports:

1) Butterfly Moving Vehicle Detector
   AN/APS/26 (Report 1021)
   Radiation Laboratory, M.I.T.

2) Butterfly, 1952
   (Report 32) Control Systems Laboratory
   University of Illinois
   By Andrew Longacre and I. W. Janney

The reason for considering a ground-based M.T.I. is that such a set would act as a sentry or surveillance instrument which could be used at night, or in obscure weather, to detect moving men, tanks, and trucks near the front lines. Such information is valuable from the standpoint of reconnaissance alone, but if the position of the moving target can be determined with sufficient accuracy in range and bearing and if the MT is within artillery range, defensive fire can be used for the reduction of the target.

GENERAL DESIGN FEATURES

This set was made by appropriate modifications of an AN/APS/19 radar as will be described below. In principle, it was designed to detect moving targets whose radial velocity, with respect to a stationary observer, was greater than 2 m.p.h. It also was required that a sector scan, centered about any chosen azimuth, and adjustable to any arbitrary angular sector from 0 degrees to 130 degrees, as well as a continuous 360-degree scan, be available.

Since in the APS/58, the range scanning is provided by the motion of the aircraft, in this ground-based unit, an additional range scanning feature was necessary. This is done by a range strobing gate which scans over an interval from R to $R+\Delta R$, where ΔR is 1/2 mile and R can be set, at the discretion of the operator, from $R = 0$ to $R = 30{,}000$ yards.

SUGGESTED TACTICAL USE

With the above features, an envisioned tactical use of this equipment is as follows. A set stationed near the front lines can survey enemy territory and detect enemy movement of troops or vehicles in any chosen angular sector, and at any range up to 30,000 yards. This can be done with sufficient accuracy (1/2 degree in azimuth and $\pm$ 10 yards in range) so that artillery fire can be brought to bear if the MT is within the range of artillery. Small arms fire can be used with equally good effect against troops. All additional equipment that is necessary is adequate communications with the artillery or defending troops since the range and bearing of any MT is quickly ascertained. A convenient location for the set would be on a hilltop or prominence overlooking a valley if the terrain is anything but flat.

The set will detect moving targets, at night or in obscure weather, as well as a visual observer would do in good clear weather. The principle limitation is that ground clutter must be present at the position of the moving target or an echo box must be added to the equipment to provide the equivalent of ground clutter.

MORE SPECIFIC DESIGN FEATURES

In Control System Laboratory Report Number I-43, "Design Of A Butterfly Sentry System," October 7, 1952, by Norman Knable (Report Number I-43 is appended as Appendix I of this report), it is shown that $\delta\theta$, the antenna beam width, should be approximately 10 degrees and it was so chosen for this set.

Further details of the "Breadboard Model" of this equipment are given in Appendix II. Included are:

1) a detailed list of components
2) available functions
3) operational procedures

Other fundamental principles may be seen from the following considerations.

Let β be the gate length. It is chosen as 500 feet for this set, since $\beta \cong \frac{c\tau}{2}$ where τ is the effective gate length and approximately equals $1\mu s$.

Also let δt, the hearing time, = 0.5 sec. From other experimental work, it is known that the integration time for the ear should be equal to or greater than 0.3 sec. Thus, δt is arbitrarily chosen as 0.5 sec.

Since the range, over which the gate strobes, is ΔR, the velocity of the strobing gate, $\alpha = \frac{d(\Delta R)}{dt}$.

Furthermore, the gate must not pass over the target in less than the hearing time, so

$$\alpha \leqq \frac{\beta}{\delta t}$$

If $\Delta\Theta$ is the angular sector to be scanned, the time for scanning such a sector is

$$t = \frac{\Delta\Theta}{\delta\Theta} \frac{\Delta R}{\beta} \delta t$$

For $\Delta\Theta$ = 130 degrees

$\delta\Theta$ = 10 degrees

ΔR = 1/2 mile

$t \cong$ 35 sec. for an antenna with a "fly-back" time equal to zero

Then the minimum velocity of a vehicle which can pass through ΔR undetected is

$$V_{min} = \frac{\Delta R}{t} \cong 52 \text{ m.p.h.}$$

or for $\Delta\Theta$ = 360 degrees

$t \cong$ 95 sec.

$V_{min} \cong$ 19 m.p.h.

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A summary of pertinent constants and symbols are given below:

	SYMBOL	CONSTANT
Pulse length	τ	1/4 and 1/2 μsec
Gate length	β	500 feet
Velocity of strobing gate in passing over ΔR	α	
Sector scan	$\Delta\theta$	Up to 130° or 360°
Range of strobe scan	ΔR	1/2 mile
Antenna beam width	$\delta\theta$	10° (and 3°)
Hearing time	δt	0.5 sec
Scan time over 130° sector	t	35 sec
Minimum velocity of M.T. not detectable under 130° scan	V_m	50 m.p.h.
PRF		1,600 p.p.s.
Power		50 K.w.
Wave length	λ	X band
Accuracy in azimuth	$\pm$ 1/2 degree	
Accuracy in range	$\pm$ 10 yards	

MODIFICATIONS OF APS/19

Of the APS/19 radar, only the transmitter-receiver unit was used.

The butterfly unit used for this equipment was a slight modification of a model used with the APS/58 radar. In order to secure maximum radar stability, the triggers for the video gate and radar modulation were derived from a clipped power supply wave form. This system would ensure a minimum jitter if the transmitter could be activated without jitter with respect to its modulator trigger. The latter is a difficult requirement, however, and in retrospect, it seems that a wiser procedure would have been to furnish triggers to the modulator which were synchronized with the power supply as before, but to trigger the butterfly timing circuits from the transmitter pulse.

The butterfly unit and its principle of operation are adequately described in the references given on page 4. It consists of a switch and storage unit which samples the video at any desired time after the transmitted pulse, and retains that video voltage for one repetition interval, at which time, it taken on the new video level and so on.

The video sampling gate is generated by a blocking oscillator (V14), which is triggered by a pulse from the plate of V12A. (See Figure 1.) This pulse occurs when the negative-going signal from the Miller Run-Down Circuit (V8) becomes less positive than the plate of V12A. (See Figure 2B.)

The conduction of the V12A results in the transfer of the run-down signal to the amplifiers and then to the Gate Blocking Oscillator. The pulse from the blocking oscillator also resets the Miller Run-Down Circuit for the next cycle which starts when the radar is triggered.

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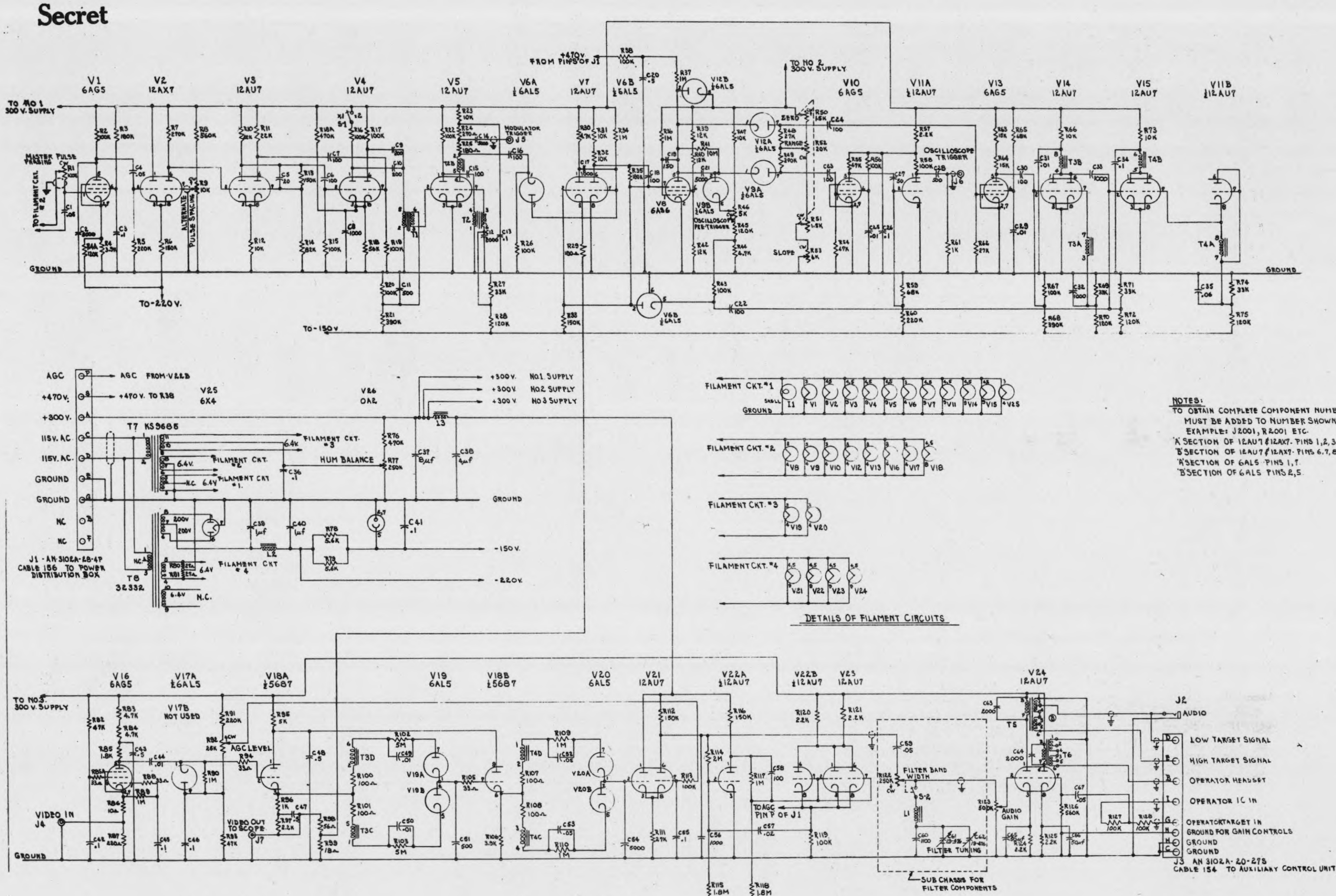

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FIGURE 1

UNIVERSITY OF ILLINOIS CONTROL SYSTEMS LAB SCHEMATIC WIRING DIAGRAM OF DETECTOR UNIT MODEL #6 FOR APS 26A			
B	DEB	3-5-52	DATE: 1-23-52 SCALE: NONE
A	DEB	2-11-52	DR BY DEB
REV.	BY	DATE	CH BY [illegible] NO. 1016

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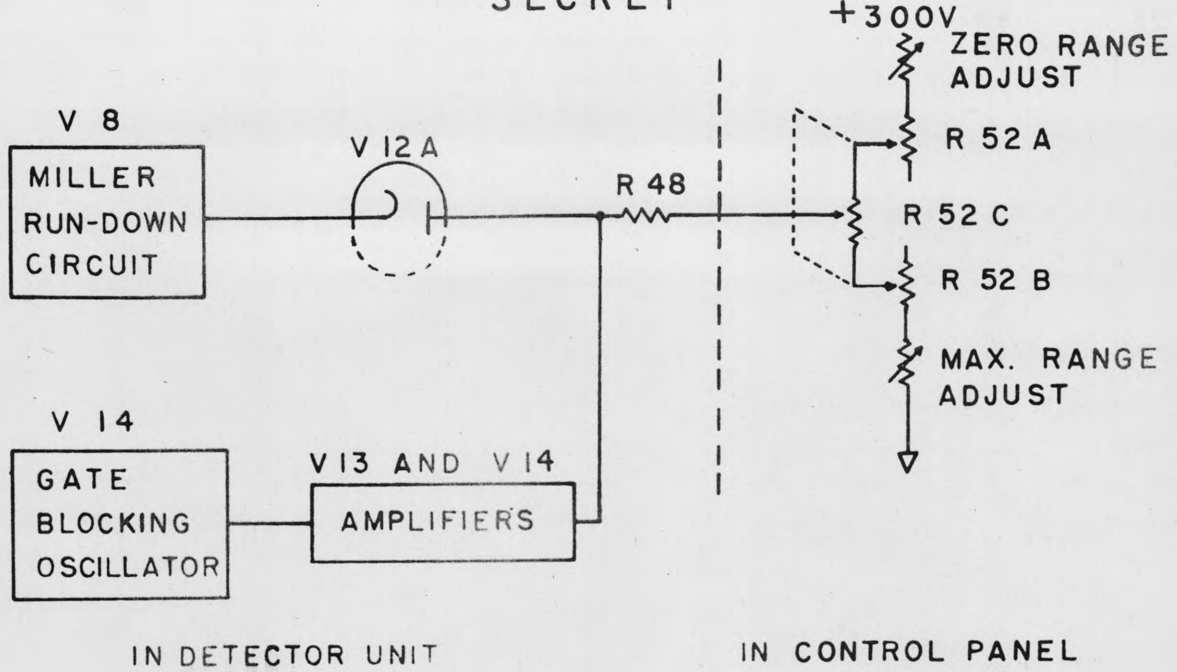
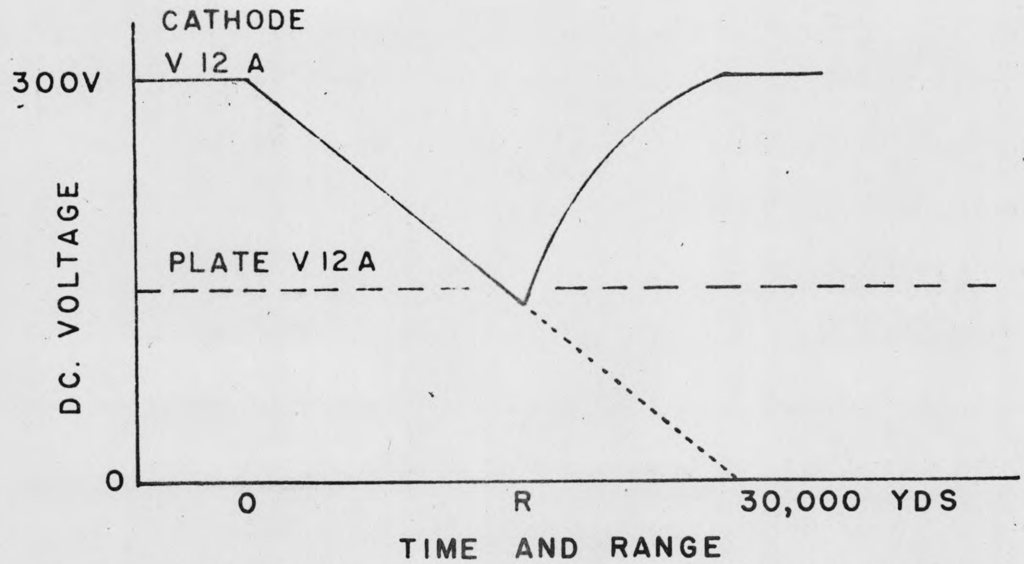


(A)



VOLTAGES PRESENT IN RANGE CIRCUIT

(B)

DETAILS OF STROBING CIRCUIT

FIGURE 2

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STROBE GATE CIRCUIT

For strobing purposes, R52 in Figure 1 is replaced by R52A, R52B, and R52C as shown in Figure 2A. R52A and B are ganged Potentiometers, calibrated in range, which set the voltage of the plate of V12A so it will fire at a time corresponding to the selected range.

R52C is a motor driven potentiometer which furnishes a sawtooth variation of the voltage of the V12A plate. This variation of voltage causes the range gate to move continuously and automatically for search operation.

R52A and R52B are electrically connected to give a constant resistance throughout the range. Thus, ΔR is constant at 1/2 mile for all ranges.

OTHER SYSTEM DETAILS

The method of obtaining sector scan and manual control of the antenna is much more elaborate than is required for this equipment, and is described in Appendix III. Therefore, it will only be necessary to point out the requirements for positioning control.

The antenna platform should be motor driven and controlled by two buttons which cause the antenna to move in two opposite circular motions for the length of time that a button is depressed. Atop this platform is located another turntable which is controlled by a second motor. Movable microswitches on this table control the sector width, and the manual controls determine the positions of the switches and whether or not sectoring or push button control is desired. The sum of the two turntable rotations gives the angular position of the target. An additional feature, the fly-back type of sector scan provided in the present system could be added also to the proposed system by switching a resistance in and out of the motor field.

Since the required beam width of the antenna was about ten degrees, it was decided to modify an APQ/13 antenna so that it had a ten-degree beam in one plane (for the search procedure) and a narrow (3^{o}) beam in the other plane, for obtaining accurate azimuth information after a target was detected. This last was accomplished by rotating the antenna about its axis of revolution.

The antenna, without its horn feed, is shown in Figure 3. Figure 4 shows the horn feed.

If there are regions where targets are most likely to appear (roads, entrances to wooded sections, etc.) a plotting table is useful in allowing the operator to limit the search to these areas. The present plotting table has a rotating arm coupled to the antenna motion. A lighted slit moves radially along the arm and is geared to the potentiometer which positions the range gate. A gear shift mechanism and three gear ratios allow the plotting table to be used with three different scale maps.

UNIVERSITY OF ILLINOIS CONTROL SYSTEMS LAB	
ASSEMBLY DRAWING OF ANTENNA AND SUPPORT	
DATE: 2-26-52	SCALE: 3/8" = 1"
DR. BY: DEB	NO. C-4000
CH. BY:	

BILL OF MATERIALS ON L-4000

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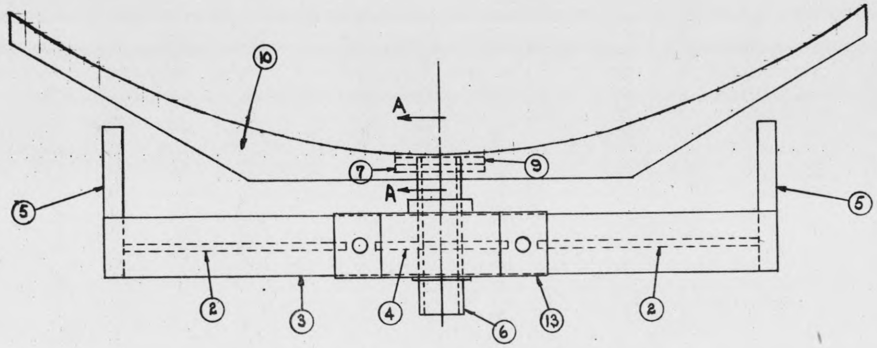

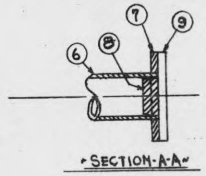

· SECTION-A-A ·

ASSEMBLY NOTE:
ITEM 6 FITS INTO ITEM 7. ITEM 8 IS WEDGED INSIDE ITEM 6, WHICH EXPANDS AND HOLDS ITEM 7 IN PLACE: THEN ITEM 9 IS ATTACHED TO ITEM 7.

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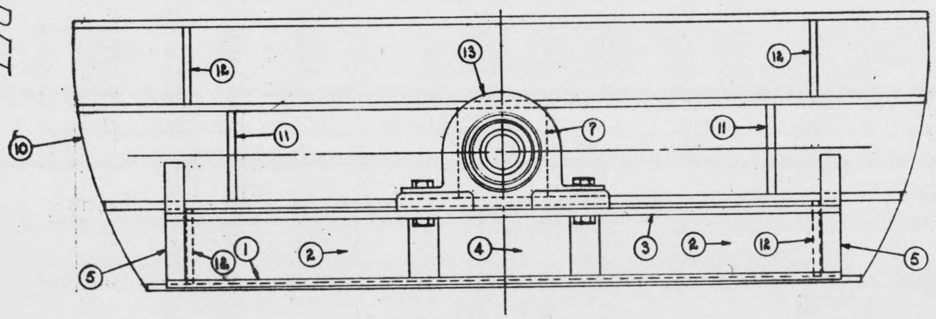

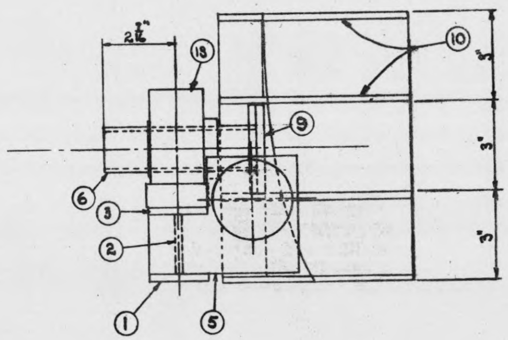

NOTE:
DISH STIFFENER BARS - ITEMS 10 - TO BE DRILLED & TAPPED #4-40 FOR MOUNTING DISH, AND DRILLED #11 TO MATCH SPACER BARS AT ASSEMBLY.

FIGURE 3

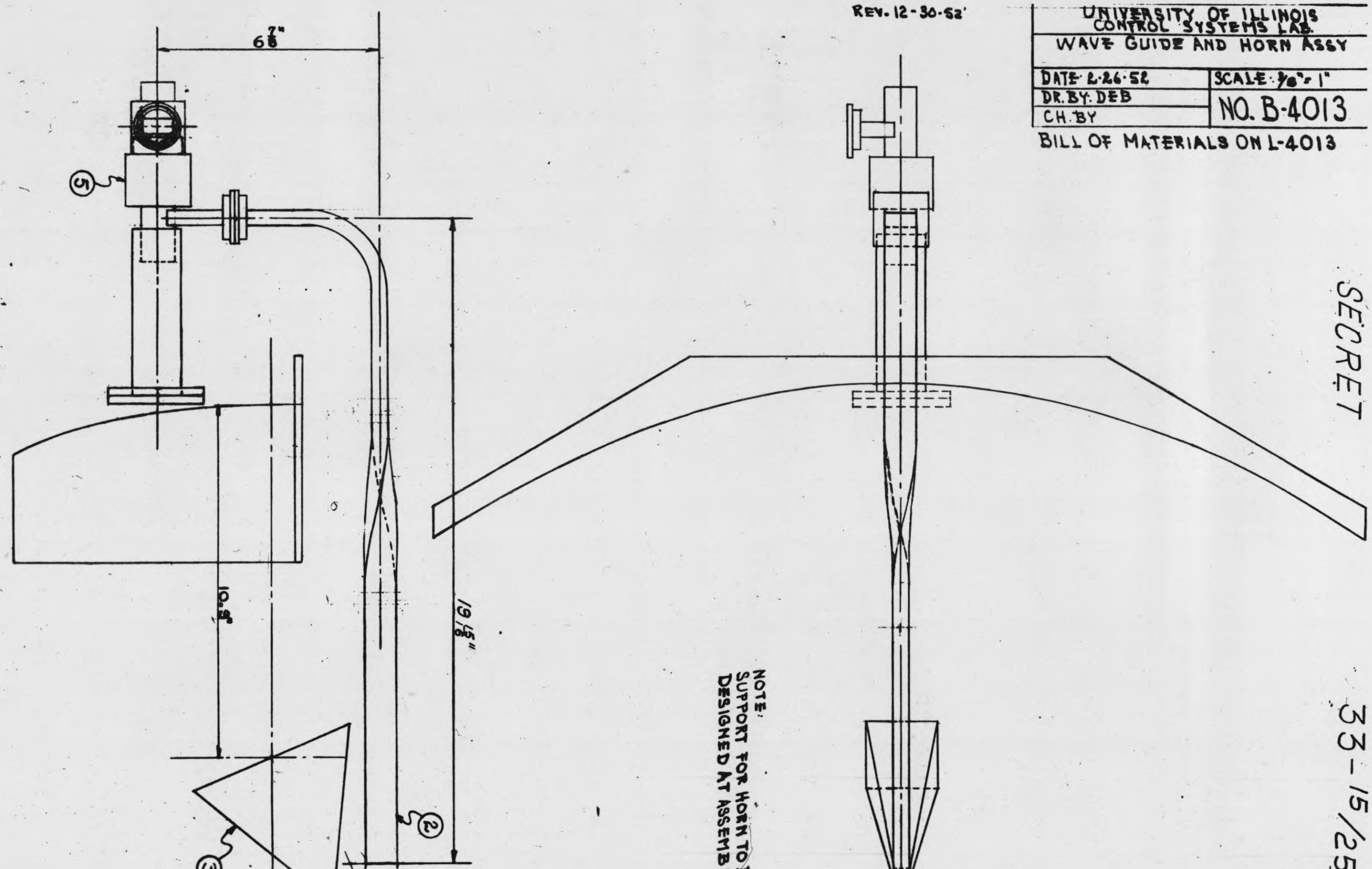

FIGURE 4

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Power for the radar and butterfly unit was furnished from a laboratory constructed power supply shown in Figure 5. Features of this supply are its well regulated 300 volt supply (0.1 per cent) and an electronically regulated modulator power supply. (Subsequent experience with the equipment indicates that the latter refinement is not necessary.)

Standard triggers for the modulator from the butterfly unit were delayed, amplified and impedance transformed to feed the 4C-35 thyratron which serves as the modulator switch. The 3 µsec delay allowed the butterfly gate to be generated before the modulator came on (Figure 6). The thyratron requires a 200 volt fast rising pulse from a low impedance source to trigger it with a minimum of jitter. The pulse here furnished was 250 v high with a .05 µsec rise time from a generator with 100 ohms internal impedance. The jitter between magnetron pulse and trigger was less than .01 µsec.

It has already been pointed out that the butterfly gates should be triggered from the transmitter pulse. This has the advantage of minimum jitter but does not allow one to look at targets of very short range. A compromise might be arranged so that both types of triggering are available, the present method used only in the emergency of close targets (500 feet or less). With such a system, it is felt that there is no disadvantage in a soft tube modulator.

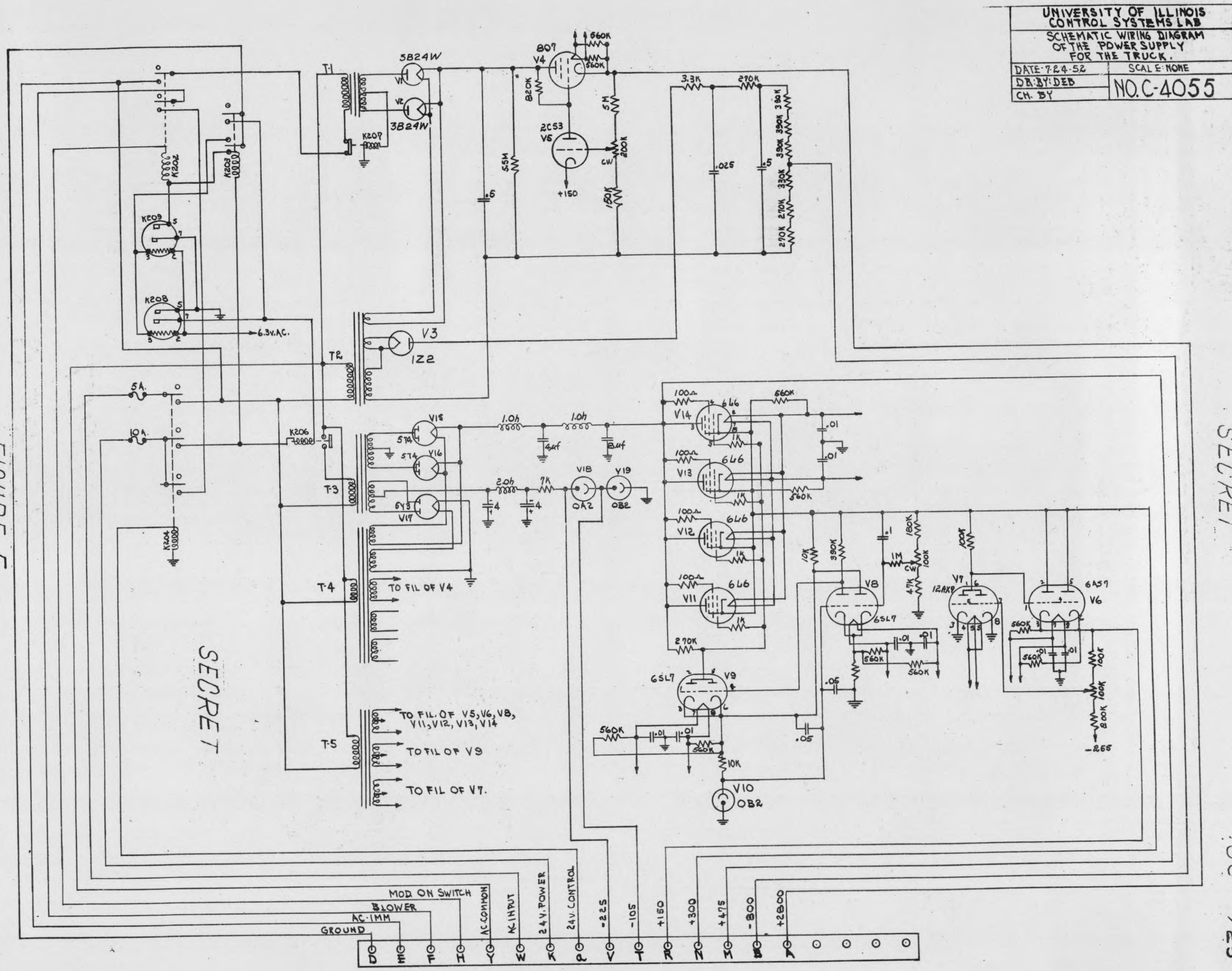

FIGURE 5

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TRIGGERING ARRANGEMENT FOR APS-19

DATE: 7-31-52	SCALE: NONE
DR. BY: DEB	NO. A-4056
CH. BY:	

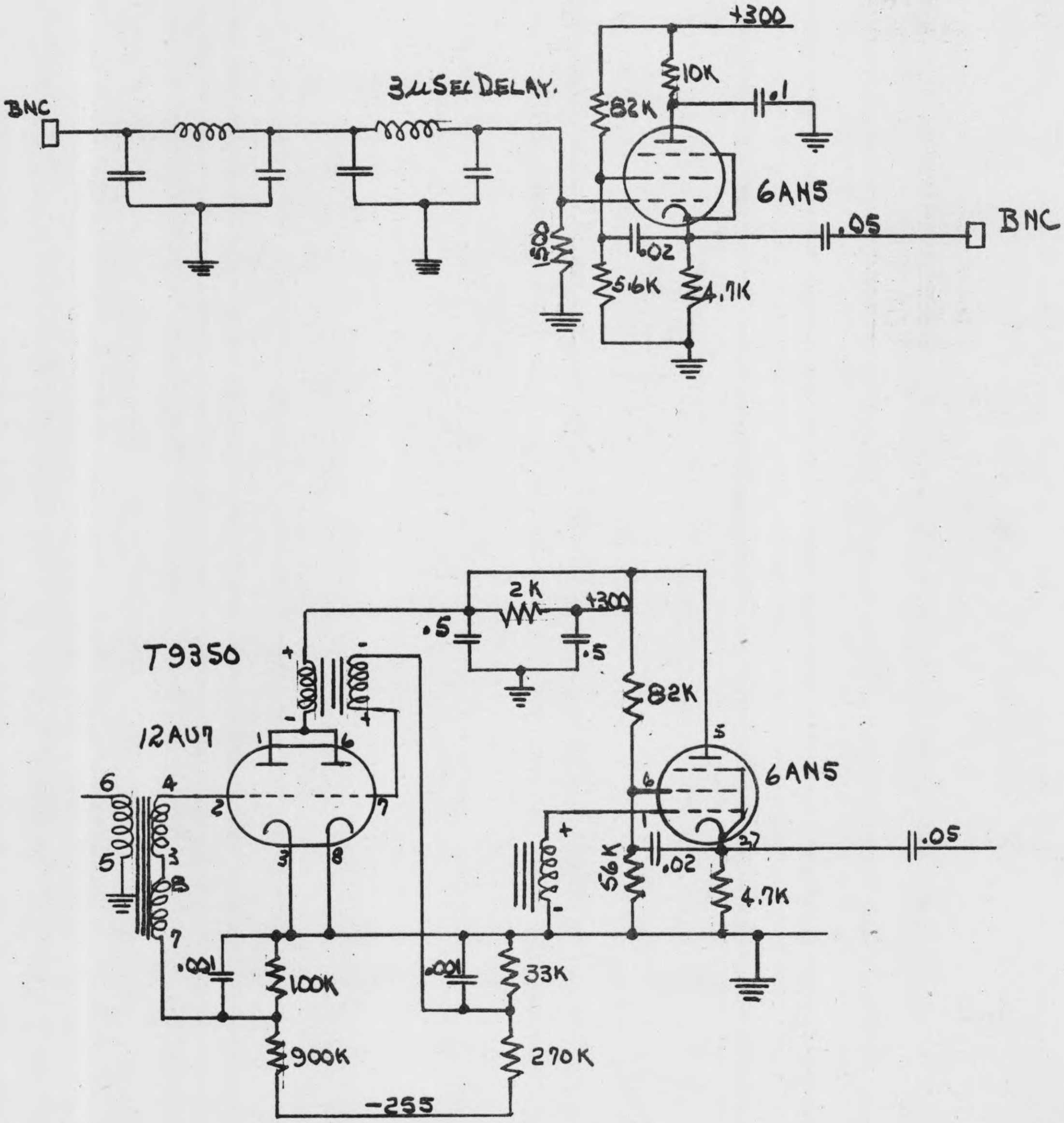

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FIGURE 6

The APS/19 radar, however, has not been designed for short range operation so that the receiver power is not adequately filtered, nor the local oscillator power. The proximity of the receiver to the modulator and the lack of a metal shield on the local oscillator are serious defects and make it difficult to keep the receiver unsaturated and the local oscillator in tune immediately after the main bang. Poor grounding in the transmitter-receiver chassis is responsible for some of the receiver paralysis.

The components of the system should include:

Required	1.	light weight antenna	22 pounds
	2.	electronic power supply . .	35 pounds
	3.	butterfly unit	25 pounds
	4.	transmitter receiver unit .	42 pounds
	5.	control box	10 pounds
	6.	400 cycle, 600 W and 28 V 100 W power generator .	25 pounds
Optional	7.	plotting table	
	8.	audio amplifier and speaker	

CONDENSED DESCRIPTION OF FIELD OPERATIONS

To place the equipment in operation, the trailer was disconnected from the truck to reduce vibration and noise in the truck. The power cable from the trailer was connected to the external receptacle located to the rear of the left cab door.

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The power units were then started and the elevator raised and locked into position. To facilitate prompt operation, the electrical equipment was placed on standby operating condition at this time.

A plumb bob on the elevator indicated when the base of the antenna was level. This leveling was accomplished by the use of four hydraulic jacks, one at each corner of the truck.

After a three-minute warm up period, the electronic equipment was placed in operation. Only two tuning adjustments were necessary. The radar local oscillator had to be tuned and the master trigger pulse synchronized with the line frequency. The local oscillator tuning was accomplished by rotating the tuning knob while observing the return on the "A" scope.

Pulse synchronization was achieved by changing the time between alternate pulses and their phase with respect to the line voltage. Proper synchronization was indicated by minimum 1,600 cps tone in the audio.

The terrain was searched by having the antenna sector scan a 10° beam at 4°/sec. In the 2.5 sec. necessary to scan a beam width, the butterfly range gate was strobed out 1/2 mile from a selected range and then returned. These actions were automatic and continuous.

At the moment of moving target detection, the operator stopped the scanning motion. The antenna returned to the center of the sector but was quickly returned to the approximate azimuth of the M.T. by the operator, using two memory disks.

With the azimuth of the M.T. determined approximately, the strobing of the gate was stopped and the beam width reduced to 3°. The range gate was manually moved out in range until it rested at the leading edge of the signal.

After final adjustment of the azimuth, the range and azimuth of the target was read directly from the disks.

Orientation of the map on the plotting table was done by one of two methods. If the location of the truck was known, one moving target such as an object traveling in a circle, was placed at a known point. The range gate would be placed on the target, giving two known points, (zero range and the location of the M.T.) for alignment of the map.

If the location of the truck was not known, two moving targets at known locations were used. This gave two points for map alignment.

At this point, it might be proper to comment on the antenna control system. In addition to one mil control of the antenna, a lobe switching scan is available and audio display system consisting of two vertical lines on an oscilloscope corresponding to alternate antenna positions. This system is now as accurate as aural presentation for locating the target, and if the audio was first passed through a filter alarm system, one could widen the lobe switching angle to obtain much greater accuracy. This comes about from the fact that the signal to noise ratio of the output voltage is increased by such a filter system allowing one to use a part of the antenna pattern which has a smaller intensity but a much greater slope. Since the antenna is already amplidyne controlled and only a small cam need be turned to move the antenna, a very simple comparison amplifier could now make this an automatic angular tracking system which could furnish continuous accurate information to a gun computer. Of course, range tracking is necessary and for this a conventional double gate circuit is adequate.

FIELD TESTS AND RESULTS

This equipment was delivered to the U.S.M.C. Equipment Board at Quantico, Virginia, August 20, 1952, for tests. Limited terrain features there made it necessary for the maximum range tests to be completed on the Skyline Drive. Both water and ground targets were observed at Quantico.

Before taking the truck down to Quantico, some fundamental data were observed in testing the equipment near the University of Illinois. The azimuth precision checked out to be less than 1/2 degree and the range precision checked out to be within plus or minus 10 yards. The latter was observed along a section line. Butterfly signals were observed at ranges less than 100 yards in both Champaign and Quantico tests. The strobe function worked equally well at all ranges.

The major portion of the testing was concerned with results from the detection of moving vehicles and men. A close approximation to typical front line conditions was chosen near Camp Upshur at the Marine Corps School, Quantico.

Controlled moving vehicles consisted of two jeeps and an armoured personnel carrier. These targets moved randomly in the 40 degree sector under surveillance. The radial component of velocity of these targets was controlled between near 0 to 10 mph, with the maximum velocity detectable limited only by the sector scan angle. All targets were quickly identified and positioned with the sector scan and strobe function of the equipment.

Moving men were observed running, walking, and sometimes crawling out of a small forest at range = 1,300 yards. The men were grouped into six-man squads. Each squad was instructed to move out of the forest in a different type of formation and movement. All formations were easily detectable with identification occurring the first time the radar beam searched their position. In practically all tests, the set operator had the troops identified and positioned before visual observers had sighted the movement. As the troops returned into the forest, butterfly signals could be heard steadily until the men had penetrated a depth of 5 to 10 yards.

The Skyline Drive test proved that the maximum range was greater than existing circuits would allow. Because of the low power return with 0.25 μsec pulses, 0.5 μsec pulses were used. A steam train was identified at 20,000 yards. The motion of the reciprocating drivers gave a characteristic butterfly signal. The trucks and cars detected at 30,000 yards could not be seen visually, but the butterfly signals indicated accelerations typical of cars and trucks.

With the set in operation on the Base docks at Quantico, various types of watercraft were observed. Uncontrolled targets consisted of freighters, oil tankers, and numerous other craft decreasing in size down to a small cabin cruiser. Maximum ranges were noted as follows:

freighters	-	20,000 to 24,000 yards
oil tankers	-	12,000 to 15,000 yards
cabin cruisers	-	6,000 to 8,000 yards

Controlled targets were a LCVP and LCM whose maximum ranges were observed as 6,000 and 10,000 yards respectively. These craft traveled from 3 to 12 knots and gave excellent butterfly signals for both radial and oblique movements. When the sea was creating heavy waves, a low frequency butterfly signal could be detected. At various times during these tests, the only possible ground clutter in the range gate was sea return.

ACKNOWLEDGMENTS

Members of the Control Systems Laboratory staff who were concerned with the development of this non-coherent, ground-based moving-target indicator are: Ronald J. Doan, Ronald S. Geiler, Robert W. Jackman, Charles E. Kassel, Norman Knable, Andrew Longacre, D. L. Markwell, Donald McGreal, A. J. Petersen, and Jack A. Ritt.

The CSL shop was responsible for the construction and assembly of various gear in the truck and trailer.

Acknowledgment is also made for the able assistance of Mrs. Carol A. Blye in preparing this report.

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DESIGN OF A BUTTERFLY SENTRY SYSTEM

Report Number R-33
Appendix I

January 1953

Prepared by:

Norman Knable

CONTROL SYSTEMS LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Contract DA-11-022-ORD-721

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SECURITY INFORMATION

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Appendix I

A truck mounted APS-19 radar set combined with a Butterfly moving target detector, a strobing gate and a scanning antenna make up the sentry equipment.

The military problem to be considered is the following. Inasmuch as the Butterfly system can see only a small range interval, what is the best method for using the equipment to prevent the approach of vehicles having a given maximum velocity? In addition to the maximum velocity, one must specify the angular sector under surveillance and the maximum time that can be alloted to perform one scan of the sector. This last quality is the maximum time required for detection after the target has entered the surveillance area.

For example, a 60 mph vehicle moves 44 feet in 0.5 second(0.5 second is the time constant of the ear and targets must be heard for at least this time interval in order to achieve maximum sensitivity) so that if our equipment had an effective gate 44 feet long, it would be necessary to have an antenna beam as wide as the sector and no scanning could be used. In order to pinpoint a target, with this type of arrangement one would have to track the target in range while continuously narrowing the beam and at the same time varying the heading. This method is obviously unsatisfactory and one then considers lengthening the gate, narrowing the antenna beam and sector scanning.

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Appendix I

At this point, it becomes necessary to put a limit on the maximum gate width. The signal-to-clutter ratio is determined by the ratio of signal return to ground return. Interclutter modulation and modulation of ground return due to radar instability varies as the area of the ground covered (beam width x gate width). Let us call the interval of range to be strobed ΔR (feet), and V (ft/sec) the maximum velocity to be detected. Then $\frac{\Delta R}{V} = \tau$, the time for a target to pass through the interval ΔR. This must be equal to the time for scanning the given sector $\Delta\theta$. Call α the velocity of the strobing gate (ft/sec). Then with a gate β (ft) we have:

$\frac{\beta}{\alpha + V} = \delta t$ where δt is the hearing time constant.

Now $\frac{\Delta R - \beta}{\alpha} = p$ where p is the time of range strobing.

Thus $\frac{p}{\tau} = \frac{\delta\theta}{\Delta\theta}$ where $\delta\theta$ is the antenna beam width.

$$\delta\theta = \frac{(\Delta\theta)p}{\tau} = \frac{\Delta\theta}{\alpha}\left[\frac{\Delta R - \beta}{\Delta R}\right]V = \frac{\Delta\theta(1 - \beta/\tau V)}{\left(\frac{\beta}{V\delta t} - 1\right)}$$

Experimentally, we have determined that for average terrain using the APS-19 radar $R(\delta\theta)\beta = k$ where R is the target range and k is a constant 5×10^7 ft.^{2} degrees for adequate signal to noise ratio on a vehicle the size of a jeep.

$$\text{Thus } \delta\theta = \frac{\Delta\theta\left(1 - \frac{k}{R(\delta\theta)\tau V}\right)}{\left(\frac{k}{V(\delta t)R(\delta\theta)} - 1\right)}$$

$$\delta\theta = \frac{-\left[\Delta\theta - \frac{k}{V(\delta t)R}\right] \pm \sqrt{\left[\Delta\theta - \frac{k}{V(\delta t)R}\right]^2 + \frac{4k\Delta\theta}{R\tau V}}}{2}$$

for $R = 10^4$ ft., $\Delta\theta = 113.5^\circ$, $\tau = 30$ sec., $V = 88$ ft/sec.

$\delta\theta = 14.7^\circ$

$p = 3.9$ sec.

$\Delta R = 2{,}640$ ft.

$\beta = 340$ ft.

$\alpha = 590$ ft.

$\delta\theta = 10^\circ$ for $\Delta\theta = 130^\circ$. In the final design, the beam width was chosen to be 10° to cover a 130° sector.

In order to get increased signal-to-noise ratio, one should decrease k as desired. However, one must keep in mind the auxiliary condition

$$\frac{\delta\theta}{\frac{\Delta\theta}{\tau}} > \delta\tau$$

The present equipment was designed from these equations to operate at a range of 2 miles with a beam width of 10°, a strobing range of 1/2 mile, and a 500 feet gate. A sector of 130° is covered in 30 seconds. For ranges smaller than 2 miles, the signal-to-noise ratio is greater than optimum and for larger ranges, the signal-to-noise ratio is reduced. When a target is located, the beam width and gate are reduced to as small values as are practical with respect to the receiver band width and maximum antenna size allowable. They are 3 degrees and .4 microseconds. The gate and antenna are now manually manipulated to give accurate target information.

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A TRUCK-MOUNTED BUTTERFLY-TYPE MOVING TARGET INDICATOR USING THE APS/19 AS A BASIC RADAR

Report Number R-33
Appendix II

January 1953

Prepared by:

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Contract DA-11-022-ORD-721

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INTRODUCTION

The equipment was constructed for the purpose of demonstrating the feasibility of attaching a butterfly moving target indicator to a typical light-weight radar set, the whole to include automatic range and angle searching with the intent of preventing the approach of any moving ground vehicles without detection. The first contact will be made at a range which depends on the disposition of opaque objects on the terrain and on the discretion of the operator.

Operation of the gear involves scanning of a sector with arbitrary angular width in azimuth and range. Thus, the area between two circles differing in radii by one-half mile and bounded by two radii of arbitrary angular displacement (usually about 100 degrees) is under continuous automatic surveillance. If a target traveling at a velocity less than sixty mph penetrates this area, it will be detected and angular motion of the antenna and range gate motion may be taken over by the operator in order to obtain the target position most accurately.

The information included in the present report is:

1. The intended use of equipment
2. List of components and description of each
3. Drawings for all electronic and mechanical equipment
4. A fairly complete description of the antenna box including advice for trouble shooting
5. Operational procedure

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LIST OF COMPONENTS

The arrangement of equipment in the truck is shown in Figure 1.

1. Transmitter-Receiver
2. Power supply box
3. Antenna
4. Control box (Radar)
5. Control box (Antenna)
6. TS-34 Scope
7. Plottong table
8. Audio amplifier and speaker
9. Tape recorder
10. VHF radio
11. Servo amplifier
12. 60 cycle gasoline powered generator
13. 800 cycle motor generator
14. 400 cycle motor generator
15. D.C. motor generator
16. Amplidyne
17. Milk truck
18. Trailer
19. Trigger box
20. Butterfly unit
21. Junction box
22. Power panel

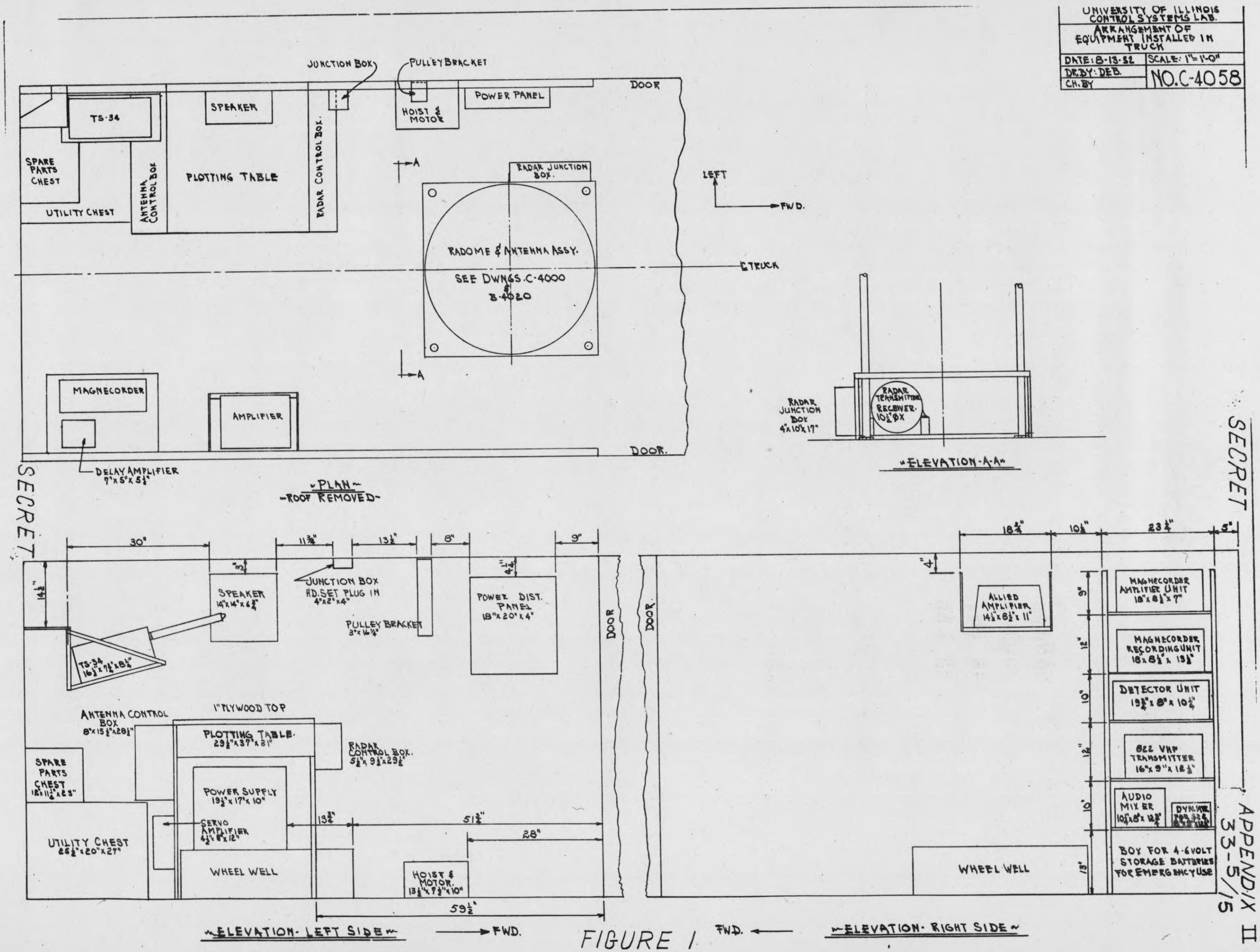

FIGURE 1

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1. The transmitter-receiver has been considerably modified. It is believed that the particular unit in the truck is a poor one in that the modulator is so badly mismatched that we are forced to pass half the modulator power into dummy resistors in order to match the magnetron. This was later corrected by replacing the pulse transformer in the APS/19 with one having the proper characteristics.

2. The APS-19 synchronizer has been replaced by a power supply box which contains several power supplies for radar and BFU. The unit is heavy and bulky since we could not secure the proper condensers and light-weight transformers for it in time for installation.

3. The antenna is a 30 inch diameter, 10.9 inches focal length paraboloid which has been cut to 10 inches in one plane so as to produce a 3 degree by 10 degree beam. The antenna is horn-fed and rests on an APQ-13 scanner. The dish may be rotated so as to secure either a 3 degree or 10 degree azimuth beam. The XMTR and antenna are mounted together in the radome on a platform which rests on the truck floor during transport and rises through a hatch in the truck roof to a position outside the truck roof during operation.

4. The radar control box is located on the right side of the plotting table and includes the following controls:

1. Standby, run, and pulse width switch
2. Gain control
3. AGC switch
4. Range strobing switch
5. Range gate position control
6. L.O. tuning
7. Plotting table lights
8. Elevator switch

5. The antenna control box is located to the left and is described in a separate section.

6. The TS-34 is located to the left of the plotting table and is used for trouble shooting, A-scope display and for audio display when the lobe switching function is used.

7. The plotting table may be used with three different map scales. The operator sits or stands before it. A lighted slit moving along a rotating arm, describes the antenna motion and range gate position.

8. An audio amplifier and mixer for voice input are used for making recordings or for transmitting the BFU audio out to a head phone bus or to a 12-inch loud speaker. It is located behind the VHF radio.

9. A tape recorder is included for recording phenomena of interest. It is located above the BFU.

10. VHF radio is located below the BFU.

11. The servo amplifier for amplifying the antenna error signal onto the amplidyne is located on the lower left side of the plotting table.

12. The 60 cycle jeep generator is the fundamental power source. It is located in the trailer.

13. The 800 cycle motorgenerator located in the trailer is run by a 60 cycle motor and furnishes power to the radar and BFU.

14. The 400 cycle generator located in the trailer is driven by a D.C. motor and furnishes current for the synchros.

15. The D.C. generator located in the trailer is driven by a 60 cycle motor and furnishes power to the switches, motors, and amplidyne.

16. The amplidyne located in the trailer, is driven by a D.C. motor and supplies current to the antenna drive motor.

17. The truck is a van type Ford equipped with a hatch for the radome, an elevator for the antenna and radome. It is equipped with leveling jacks and trailer attachment.

18. The trailer houses the heavy generating equipment. A framework has been constructed so that in transport it is protected by a canvas covering.

19. The trigger box delays the BFU trigger to the modulator so that gates in the BFU may have time to be generated. It is located behind the tape recorder.

20. The BFU assimilates the radar video, disgorging only that information pertaining to the moving targets. It is located in the rear ATR rack of the truck.

21. The junction box is attached to the side of the elevator and serves as a point of interconnection of the various components. Test voltages and wave forms are also available at this box.

22. The power panel is located on the inside wall of the truck and contains the meters and fuses for 60 cycle, 400 cycle D.C., 800 cycle power.

FUNCTIONS AVAILABLE

I. A radar transmitter and receiver with 1/4 microsecond and 1/2 microsecond pulse widths of 50 KW at X band and repetition rate of about 1,600 cycles.

II. An antenna with $3^{\circ} \times 10^{\circ}$ beam widths rotatable about the paraboloid axis of symmetry. Also rotatable about a vertical axis and about an axis perpendicular to the plane of the vertical direction and the paraboloid axis of symmetry. Angular accuracy of motion about the vertical axis is indicated on dials to an accuracy of one mil. The tilt and paraboloid axis rotation are effected by switches. The azimuth motion is continuously controlled by a knob through a torque amplifier.

Automatic motions available are:

1. Continuous rotation in azimuth
2. Sector scanning with fly back in azimuth
3. Lobe switching in azimuth

The heading about which sectoring or lobing occurs is displayed.

III. A BFU which furnishes the radar trigger, receives the radar video, gates a 0.2 microsecond portion of it at arbitrary range and filters out all components of the resultant signals except those due to variation in return from pulse to pulse due to the phase shift of a moving target with respect to a fixed one, such as the ground return. A moving target is indicated when an audio tone from 100 to 1,600 cycles is heard in the headphones or loud speaker.

The range gate is indicated to an accuracy of ten yards. It may be manually operated and may be caused to strobe through a half mile range interval in 2.5 seconds, about an arbitrary range. The antenna speed has been adjusted so that it rotates one beam width (10°) in 2.5 seconds. Thus all targets are covered and with the effective 1.0 microsecond gate employed in the sector scanning procedure, the target may be heard for about 1/2 second.

OPERATIONAL PROCEDURE

I. Placing the radar in operation.

1. Unlatch the trailer from truck, level the truck.

2. Remove trailer tarpaulin, connect power cable from trailer to side of truck, lower tailgate. Start jeep engine, throw both trailer panel switches to up position. Now turn on truck power panel switches.

3. Open roof hatch and raise elevator by switch on radar control box. Place safety pins in proper holes after elevation.

4. Turn radar switch on radar control box to standby. Turn on audio amplifier. Now observe at junction box, the indicator trigger (a measure of the magnetron current). Trigger scope from scope trigger on junction box. Terminate scope cable in 100 ohms. When the radar is ready to come on, three minutes later, rotate the switch from standby to 1/4 microsecond. Look at pulse on fast sweep and adjust the BFU controls, synch spacing and phasing, to make the wave form appear jitter free and as a single pulse. Be sure that the pulse is also satisfactory in the 1/2 microsecond position.

5. Now connect the scope input to the junction box video. Tune in targets by tuning control and gain control on radar control box. AGC switch should be off. The A scope is used for tuning. The step on the trace (use medium sweep) corresponds to the approximate position of the butterfly gate. (At this point, the truck should be oriented. However, to avoid confusion, we will assume orientation and describe that step last.)

6. Turn power and antenna switches on, scan switch in neutral position, search switch off, and beam switch in 10 degree position. Operate tilt switch so that tilt is zero. Turn range pot to position desired and turn on strobing switch on radar control box.

7. Manually rotate antenna by turning 31-speed knob until it points along a heading which will be the center of the sector the antenna is to scan.

8. Unclamp the heading marker (the plastic dial with the red line mounted just above the 1-speed heading dial) using the thumb screw on the heading knob, and rotate it until the red line is under the black hairline--or over the heading of the center of the sector. This red line remembers this heading. Clamp marker with thumb screw.

9. Throw scan switch to sector position. Observe that the red line on the sector scan dial under the 1-speed heading dial begins to follow the antenna in its sector scanning motion and that the black hairline is the center of this oscillation.

10. Turn Sector Scan Angle Dial to desired sector width. Push down on the knob before turning. Select smaller sector widths only when the antenna is sector scanning. This dial operates mechanical limits which require the controlling mechanisms to be moving before their positions can be changed.

11. If a target is heard during sector scanning, throw Scan switch to neutral position. This stops the sector scan dial so the red line indicates the approximate heading of the target relative to the center of the sector (hairline). Throwing this switch also causes the antenna to swing from the heading it had when the target was observed to the heading of the center of the sector.

12. Manually rotate antenna by turning the 31-speed knob in such a direction as to cause the red heading marker line on the plastic dial to line up with the red line on the sector scan dial. As these red lines approach alignment, the target signal will be heard again.

13. Turn strobing switch off and turn range pot C.W. to pick up target.

14. Maximize range, tilt, azimuth controls.

15. Now throw beam switch to 3 degree position. Repeat controls in 14.

16. Throw scan switch to Lobe position. Antenna will move 2 degrees from the heading indicated by the heading dials, remain in that position for about a second,

and then switch to a position 2 degrees on the other side of the heading and remain there for about a second.

17. While the antenna is lobe switching, the heading should be adjusted by rotating the 31-speed knob until the magnitude of the target signal in each lobe switch position is observed on the TS-34 scope to be the same.

18. The correct target heading is now read on the heading dials under the black hairline to the nearest 0.1 degree.

19. If continuous rotation instead of sector scanning is used, there is no need to line up red lines when the antenna stops for the antenna points at the target.

ORIENTATION OF TRUCK

Before the truck radar is put into operation, it is necessary for the position of the truck to be known relative to fiduciary points in the surrounding terrain. Such points together with the position of the truck (T) and gun positions (G) are surveyed and a map is constructed showing their relative positions. The radar is then turned on and the antenna is rotated until a whirligig mounted at one of these known points is detected. A line is then drawn on the map from the truck's position to this point and the angle (θ) between this line and the verticle grid line of the map is measured.
The 1-speed and 36-speed heading dials are unlocked from

their shafts and rotated until this angle is read under the hairline. The dials are then clamped to their shafts and the antenna is now oriented with the map. A zero reading under the hairline will now indicate a heading pointing toward the top of the map parallel with the vertical grid lines.

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ANTENNA SERVO CONTROL SYSTEM

Report Number R-33
Appendix III

January 1953

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Contract DA-11-022-ORD-721

Numbered Pages: 64

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SECURITY INFORMATION

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ABSTRACT

This paper describes the electrical and mechanical operation of the antenna servo system. This system enables the antenna to be rotated in elevation, azimuth, and about the axis of the antenna dish. Azimuth motion includes continuous rotation at a search speed of 4°/sec and a saw tooth sector scanning motion over a sector of controllable width from 5 degrees to 120 degrees. A continuous heading indication is provided for both types of azimuth motion. This paper also includes zeroing and trouble shooting procedures necessary for maintenance of this system in the field.

ELECTRICAL OPERATION

GENERAL

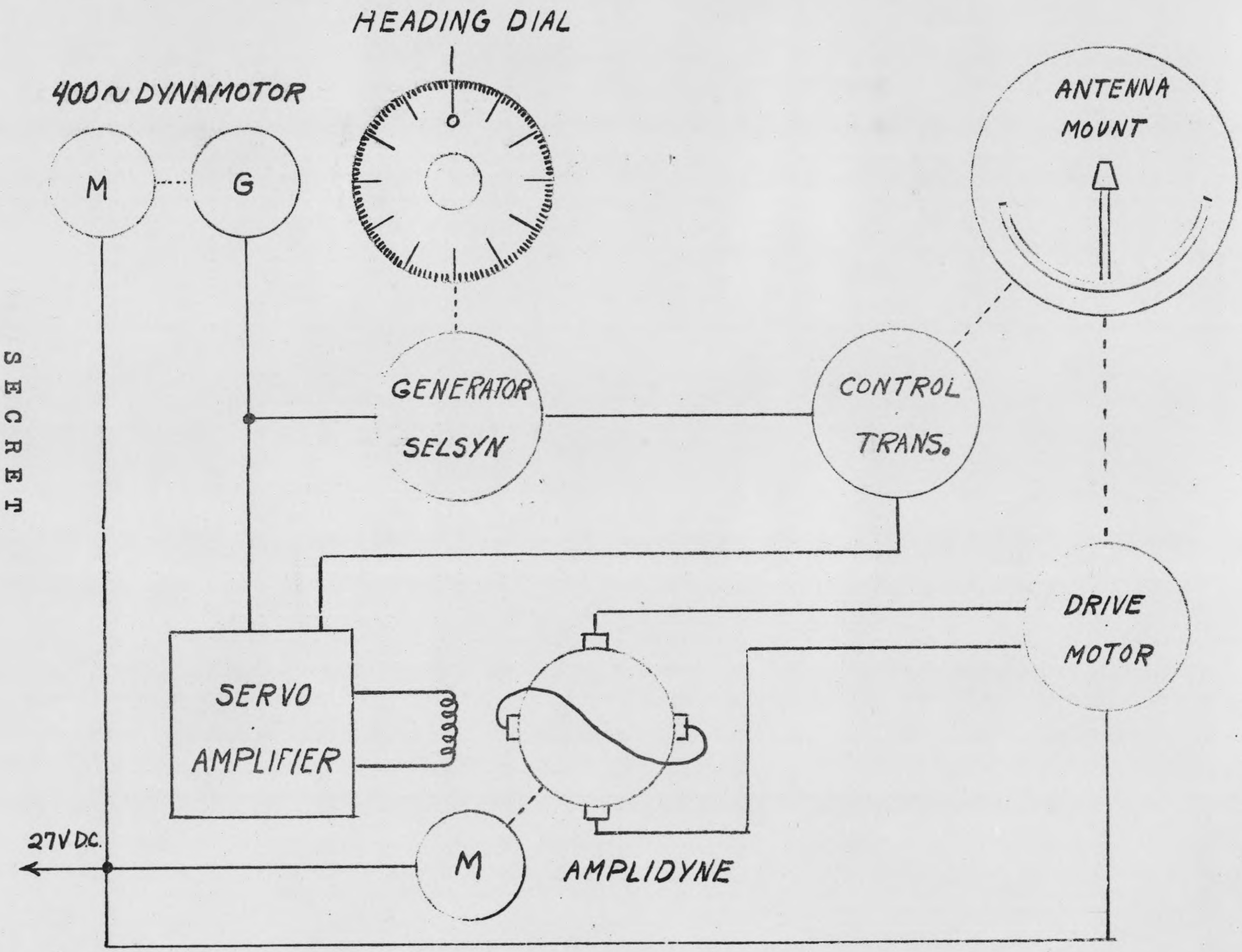
The antenna servo control system provides a means of remotely controlling the motion of the antenna in azimuth, elevation, and about the axis of the antenna dish. Rotation of the antenna dish about its axis is referred to as beam switching because the dish is moved through 90 degrees from a position generating a 10-degree beam in the horizontal plane to a position generating a 3-degree beam. This motion is controlled by the beam-switch located on the antenna servo control box which operates a d-c motor geared to the antenna dish. Change in elevation or tilt is similarly controlled by a tilt switch on the antenna servo control box which operates the reversible tilt motor on the antenna mount. This motor enables the antenna to be elevated or depressed 20 degrees from a horizontal plane.

The motion of the antenna in azimuth is more complex than beam switching or changing elevation. This motion includes search or continuous rotation, scanning a sector of controllable width from 10 to 120 degrees, and lobe switching or switching the antenna's position 2 to 3 degrees on either side of a defined heading. A means of displaying the antenna's heading, and consequently, the azimuth position of a target is provided with readings accurate to 0.1 degree.

Both the accuracy and variety of azimuth motion are made possible by a two signal positioning control servo system. The components of this system including the power elements are a 115 volt 400 cycle dynamotor, 1-speed and 31-speed 400 cycle selsyn systems, a servo amplifier, amplidyne motor-generator set, and the antenna azimuth drive motor.

Figure 1 is a simplified block diagram illustrating the operation of these basic components. The 400 cycle dynamotor supplies power to the generator selsyn and to the servo amplifier. During the system's operation, the generator selsyn, which is geared to the heading dial, is constantly sending electric impulses or signal voltages to the control transformer which is geared to the antenna. These signal voltages indicate the position of the heading dial relative to a reference mark or hairline. The control transformer compares the position or heading of the antenna with these incoming signals or the position of the heading dial. If the heading dial and antenna are pointing in the same direction or are in alignment, no further action takes place in the system. If, however, the heading dial is rotated out of alignment with the antenna, the control transformer "sees" this error and sends out an error signal to the servo amplifier the value of which is determined by the amount of disalignment.

FIG. 1- BLOCK DIAGRAM OF ANTENNA SERVO CONTROL SYSTEM



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The servo amplifier amplifies and rectifies this error signal and sends it to the control field of the amplidyne motor-generator set. The amplidyne acts as a power amplifier generating a large d-c output as compared with the d-c input from the servo amplifier. This output is fed to the azimuth drive motor which rotates the antenna into alignment with the heading dial.

THE SELSYN SYSTEMS

As a preliminary to a more detailed discussion of the servo system, it is necessary to study the controlling selsyns and to understand the need for a two speed or two signal selsyn system. There are three types of selsyns used in this control system: a generator selsyn, a differential selsyn, and a control transformer. All three have similar physical characteristics: a stator, rotor, and slip rings, and resemble small a-c motors. The generator selsyn and control transformer each have three stator terminals and two rotor terminals located at one end. The differential selsyn is slightly larger than the other two types and has three stator terminals and three rotor terminals located at one end. All three types of selsyns have different electrical characteristics and are not interchangable. They are designed to operate at 400 cycles and will be damaged if operated at lower frequencies.

The control of the search motion or continuous rotation of the antenna requires two of these three types: the generator selsyn, and the control transformer. Figures 2, 3, and 4 illustrate the operation of these selsyns. As can be seen in Figure 2, the generator selsyn has a Y-wound stator and a single coil rotor. The dynamotor impresses 115 volts 400 cycles across the rotor which causes a field to develop parallel to the axis of the coil. This field reverses its direction 180 degrees each cycle. For the purpose of illustration, we will consider an instantaneous direction of this field and represent it by an arrow. This field induces voltages in the stator legs whose magnitudes vary as the cosine of the angle the field makes with the axis of each leg. The voltage observed across any two leg terminals varies as the cosine of the angle the field makes with the flux linkage between the leg. These linkages are represented by dotted lines in Figure 2. The stator is so designed that the maximum voltage that can be observed across any two stator terminals is equal to one half the input voltage across the rotor or 115 volts/2 = 57.5 volts. Figures 2, 3, and 4 show the various voltages that are developed across the stator terminals for different positions of the rotor.

The stator of the generator selsyn is electrically connected to the stator of the control transformer. The

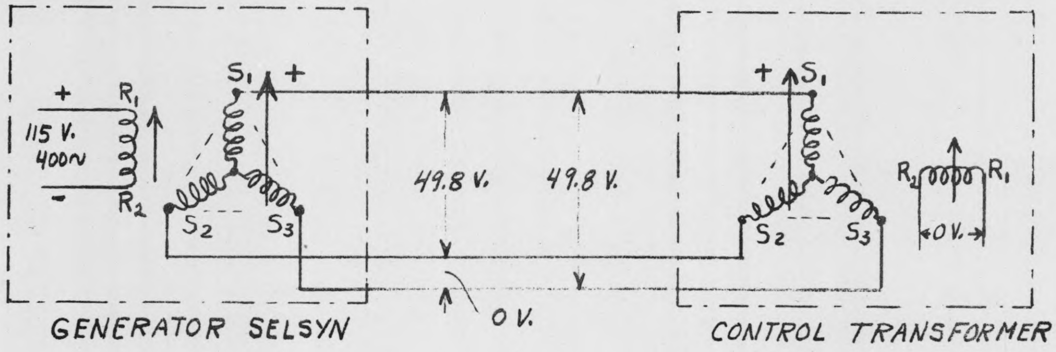

FIG. 2 - VOLTAGES IN STATORS OF GENERATOR SELSYN AND CONTROL TRANSFORMER WITH ROTORS IN ZERO POSITION.

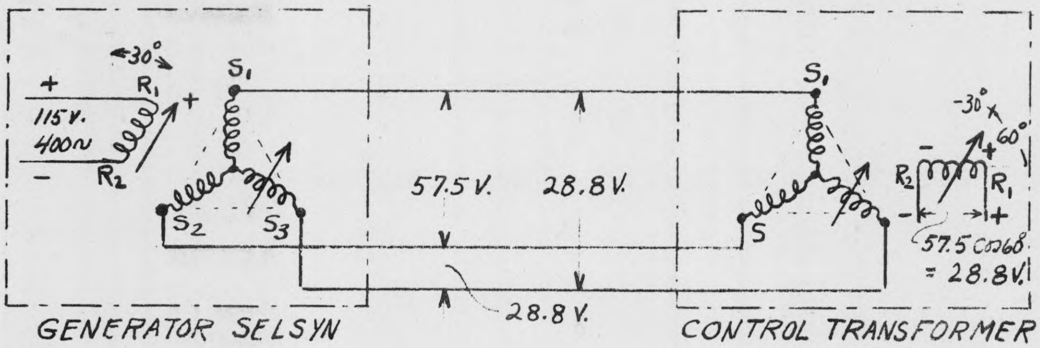

FIG. 3 - HOW 30° CLOCKWISE MOVEMENT OF GENERATOR ROTOR AFFECTS MAGNITUDE AND POLARITY OF VOLTAGES IN CONTROL TRANSFORMER ROTOR.

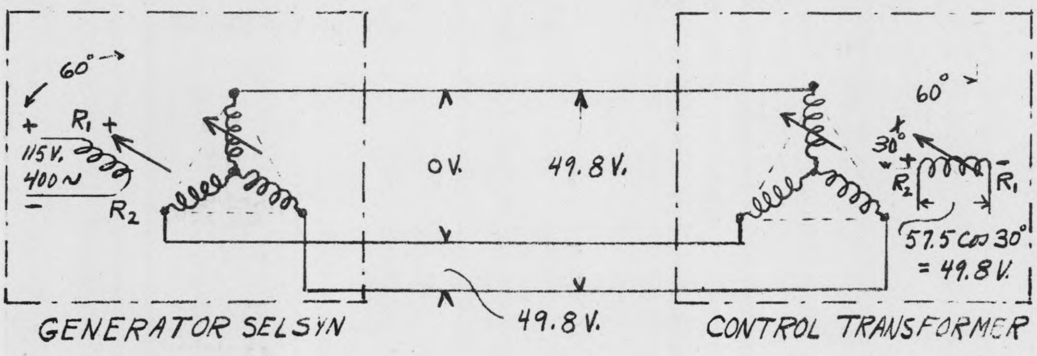

FIG. 4 - HOW 60° COUNTERCLOCKWISE MOVEMENT OF GENERATOR ROTOR AFFECTS MAGNITUDE AND POLARITY OF VOLTAGES IN CONTROL TRANSFORMER ROTOR.

resulting voltages impressed across the legs of the control transformer stator create a field which is identical in magnitude and direction to the field developed in the generator selsyn. This field induces a voltage in the rotor of the control transformer whose magnitude varies as the cosine of the angle the field makes with the axis of the rotor.

In the selsyn system, the rotor of the generator selsyn is geared to the heading dial and the rotor of the control transformer is geared to the antenna mount. This gearing is so arranged that when the heading dial and antenna are in alignment, the field developed in the generator selsyn is at right angles to the rotor of the control transformer and the induced voltage is zero. (See Figure 2).

If the heading dial is rotated 30 degrees clockwise out of alignment with the antenna, the field in the control transformer also rotates 30 degrees, making an angle of 60 degrees with the rotor. The voltage across the rotor induced by this field is 57.5 cos 60 = 28.8 volts.

It is important to note that for the particular half cycle we are considering, the field is in the position shown in Figure 3. This position causes R2 to be positive and R1 to be negative. When this error signal of 28.8 volts enters the servo amplifier, its polarity is compared with the polarity of the 400 cycle power from the dynamotor.

This phase comparison determines the direction or polarity of the d-c output from the servo amplifier which in turn determines the output polarity from the amplidyne and the direction the azimuth drive motor will turn the antenna. In this case, the polarity is such as to cause the drive motor to rotate the antenna clockwise into alignment with the heading dial.

Figure 4 illustrates what happens when the heading dial is rotated counter-clockwise 60 degrees. For the same half cycle as considered in the above case, the field makes an angle of 30 degrees with the rotor axis causing R_1 to be positive and R_2 negative and the induced voltage = 57.5 cos 30 degrees = 49.8 volts. This polarity of the error signal causes the drive motor to rotate the antenna counter-clockwise into alignment with the heading dial.

In the system described above, the angular displacement of the antenna is equal to the angular displacement of the selsyn rotors. Such a system in which there is a one to one ratio between the speeds of the selsyns and antenna is referred to as a 1-speed selsyn system.

<u>31-SPEED SYSTEM</u>

Selsyn generators and control transformers are subject to small electrical errors due to manufacturing tolerances. If, in a 1-speed system the cumulative electrical error is 1/2 degree, there will be a 1/2 degree error in positioning the antenna and in reading the heading of a possible target.

Such error is undesirable if great azimuth accuracy is desired.

To insure greater azimuth accuracy and smoothness in tracking a 31-speed selsyn system is added to the 1-speed system. With this system, if the cumulative electrical error is 1/2 degree, the resulting error in the antenna heading is 1/2 degree x 1/31 = 1/62 degree, which is much closer to the desired accuracy. The 31-speed system is electrically identical to the 1-speed system except it is geared to rotate 31 revolutions for one revolution of the antenna.

Figures 5 and 6 illustrate the operation of this system. When the antenna is out of alignment with the heading dial, error signals are fed to the servo amplifier from both the 1-speed and 31-speed control transformer. When the angle of disalignment is greater than 3 degrees, the 1-speed error signal controls the output of the servo amplifier. When the angle becomes less than 3 degrees, the neon tubes in the amplifier switch to the 31-speed system and the final alignment is accomplished with considerable accuracy. During slow tracking when the heading dial is rotated slow enough for the antenna to follow, the incremental disalignment angle is less than 3 degrees and the 31-speed system is always in control. This results in a smooth tracking motion.

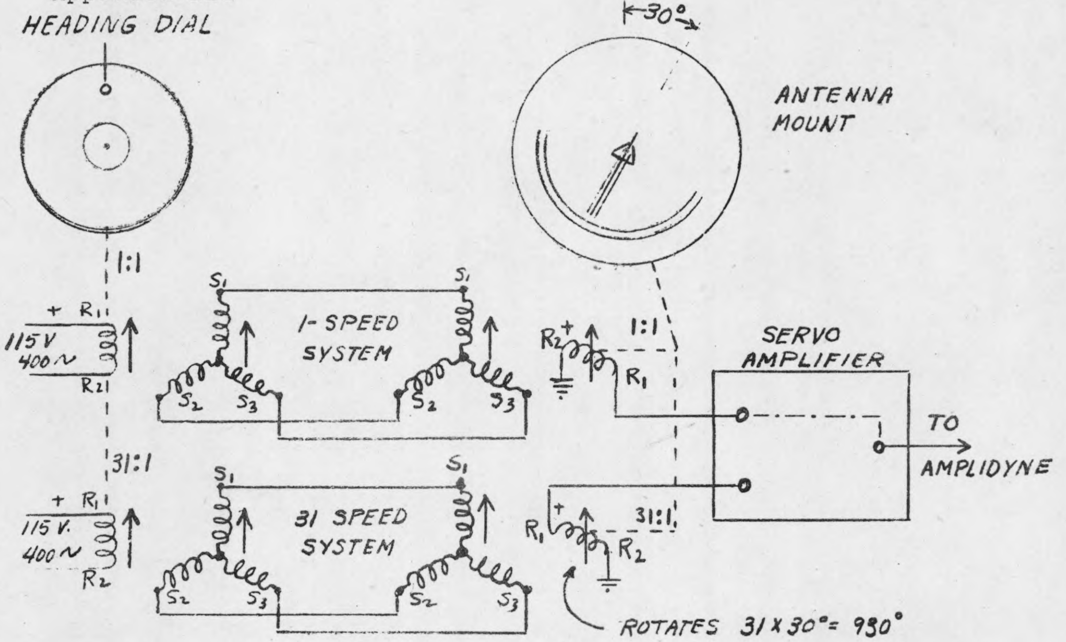

FIG. 5 - 1-SPEED CONTROL FOR DISALIGNMENT ANGLES GREATER THAN 3°

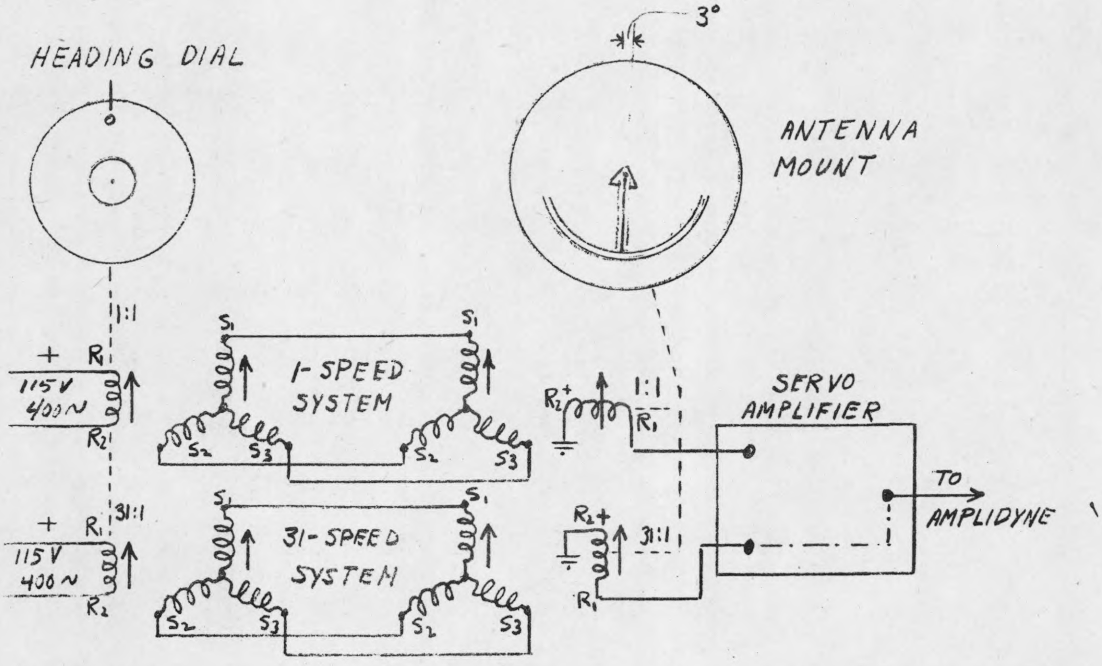

FIG. 6 - 31-SPEED CONTROL FOR DISALIGNMENT ANGLES OF 3° OR LESS

So far, this discussion has been concerned with the selsyn systems controlling a search motion of the antenna or a motion involving a change in heading. Two other types of azimuth motion are required of the antenna: sector scanning and lobe switching.

SECTOR SCANNING AND LOBE SWITCHING

Sector scanning involves moving the antenna clockwise at about 4 degrees/second through a sector of controllable width (10 degrees-120 degrees) and then moving it counter-clockwise back through the same sector with the maximum speed of the system. It is also necessary for the heading dial on the antenna servo control box to read the heading of the center of this sector (Figure 7). To accomplish this type of motion, it is necessary to cause the field in the 1-speed control transformer to move through this same sector angle oscillating about the heading defined by the rotor of the 1-speed generator selsyn. This is achieved by means of a differential selsyn switched into the circuit between the generator selsyn and the control transformer when the scan switch is thrown to the sector position. (Figure 8 and Figure 9 and Figure 10). The differential selsyn consists of a Y-wound rotor and a Y-wound-stator with three rotor terminals and three stator terminals mounted at one end. If the rotor of the differential selsyn is in alignment with the differential selsyn stator, (as shown in Figure 8)

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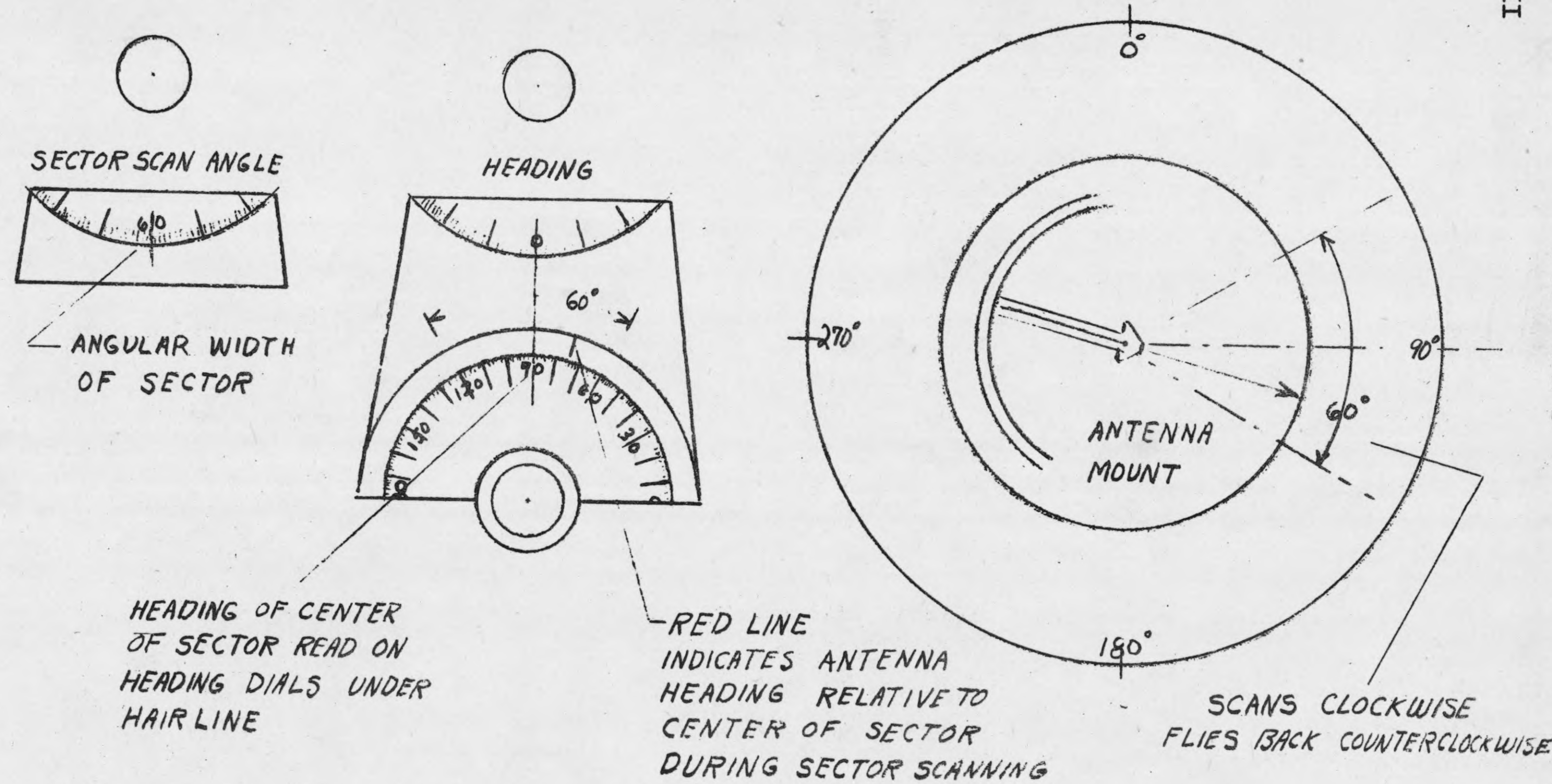
FIG. 7. - SECTOR SCANNING OPERATION



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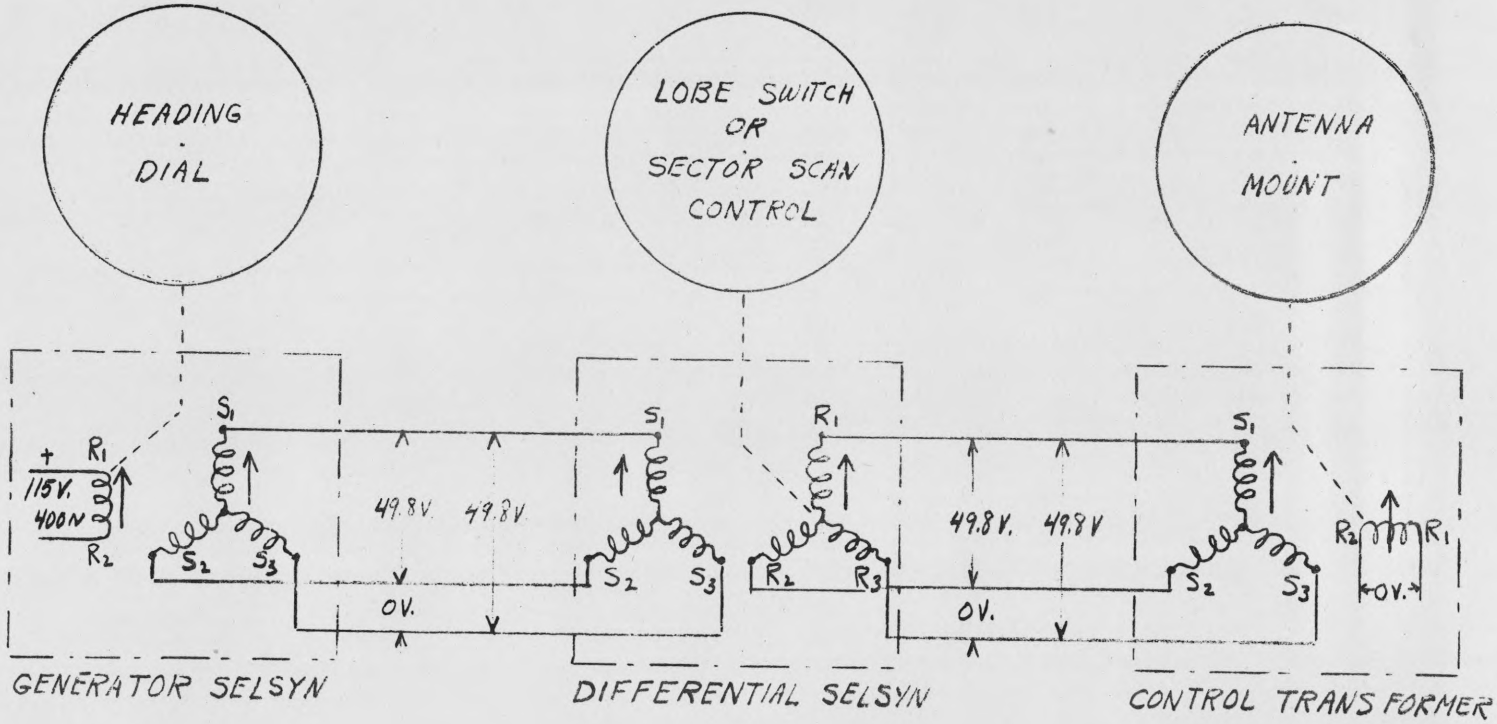

FIG. 8 - ELECTRICAL CONNECTION OF DIFFERENTIAL SELSYN INTO SELSYN SYSTEM

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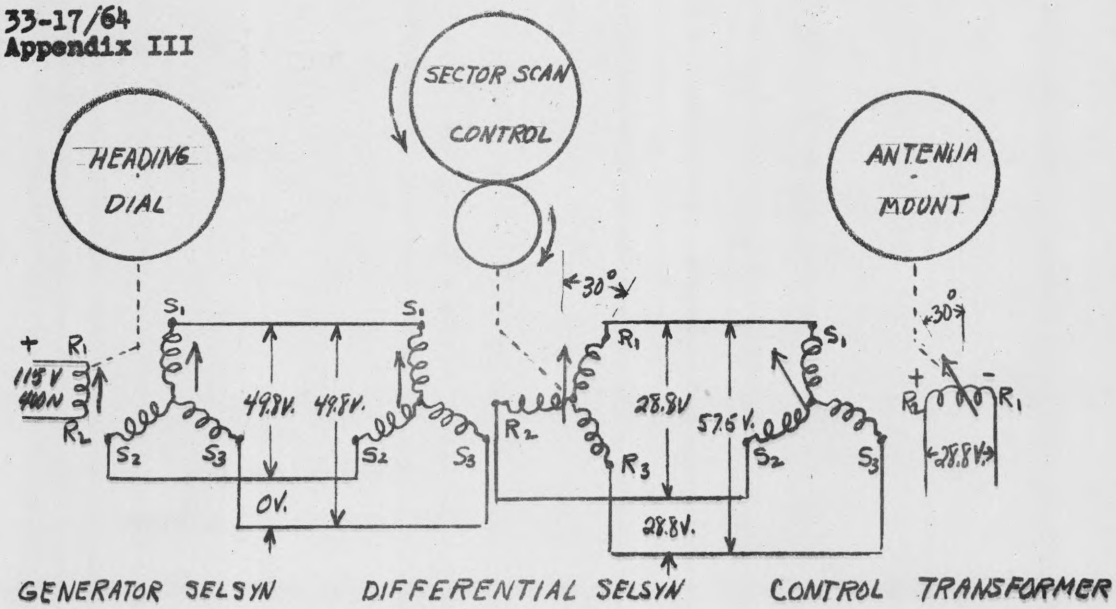

FIG. 9 - HOW 30° CLOCKWISE MOVEMENT OF DIFFERENTIAL SELSYN ROTOR AFFECTS MAGNITUDE AND POLARITY OF VOLTAGE IN CONTROL TRANSFORMER ROTOR

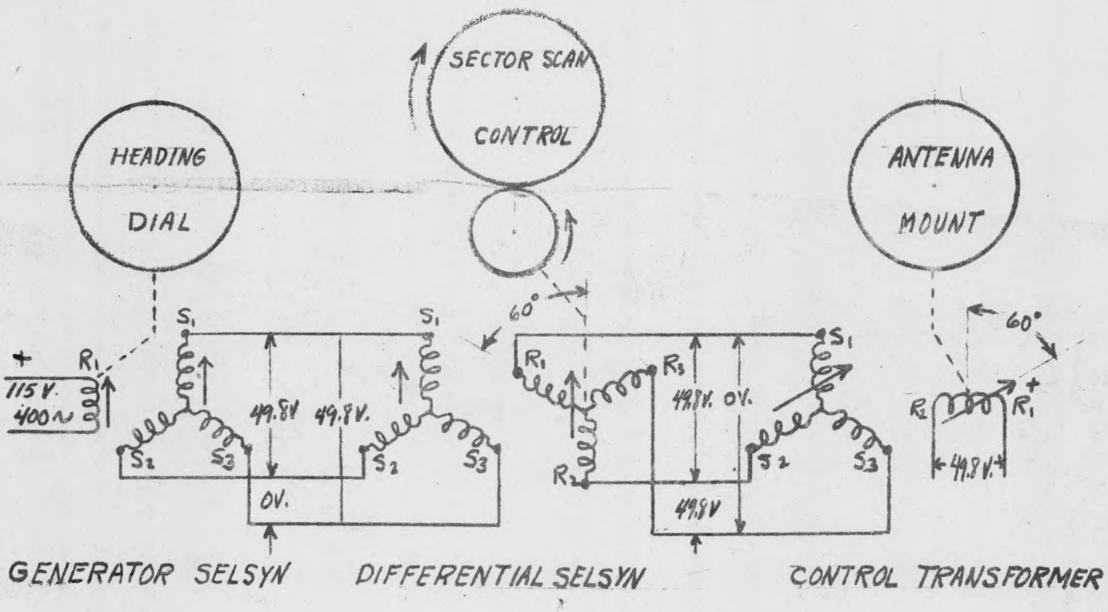

FIG. 10 - HOW 60° COUNTERCLOCKWISE MOVEMENT OF DIFFERENTIAL SELSYN ROTOR AFFECTS MAGNITUDE AND POLARITY OF VOLTAGE IN C.T. ROTOR

the field developed by generator selsyn will be transmitted to the control transformer without any change in heading. If the generator rotor is fixed in this heading and the differential selsyn rotor is rotated clockwise 30 degrees, the field transmitted to the control transformer will rotate clockwise 30 degrees (Figure 9). Similarly, a counter-clockwise rotation of the differential rotor causes counter-clockwise motion of the field in the control transformer and a corresponding motion of the antenna (Figure 10). By causing the rotor of the differential selsyn to sector scan about the heading defined by the generator rotor, the antenna follows with a corresponding motion. Rotating the heading dial during sector scanning merely changes the heading of the sector.

During sector scanning, the slow clockwise tracking motion can be controlled by a 31-speed differential selsyn. The fly back motion imparted to the differential selsyn is faster than the antenna can follow and the incremental error is greater than three degrees. Thus, the sector scan fly back requires a 1-speed differential selsyn for control.

Lobe switching is similar to sector scanning in that the antenna moves the same number of degrees on either side of the heading defined by the generator selsyn. In this case, the antenna moves rapidly to positions about 2 degrees on either side of the heading but remains in

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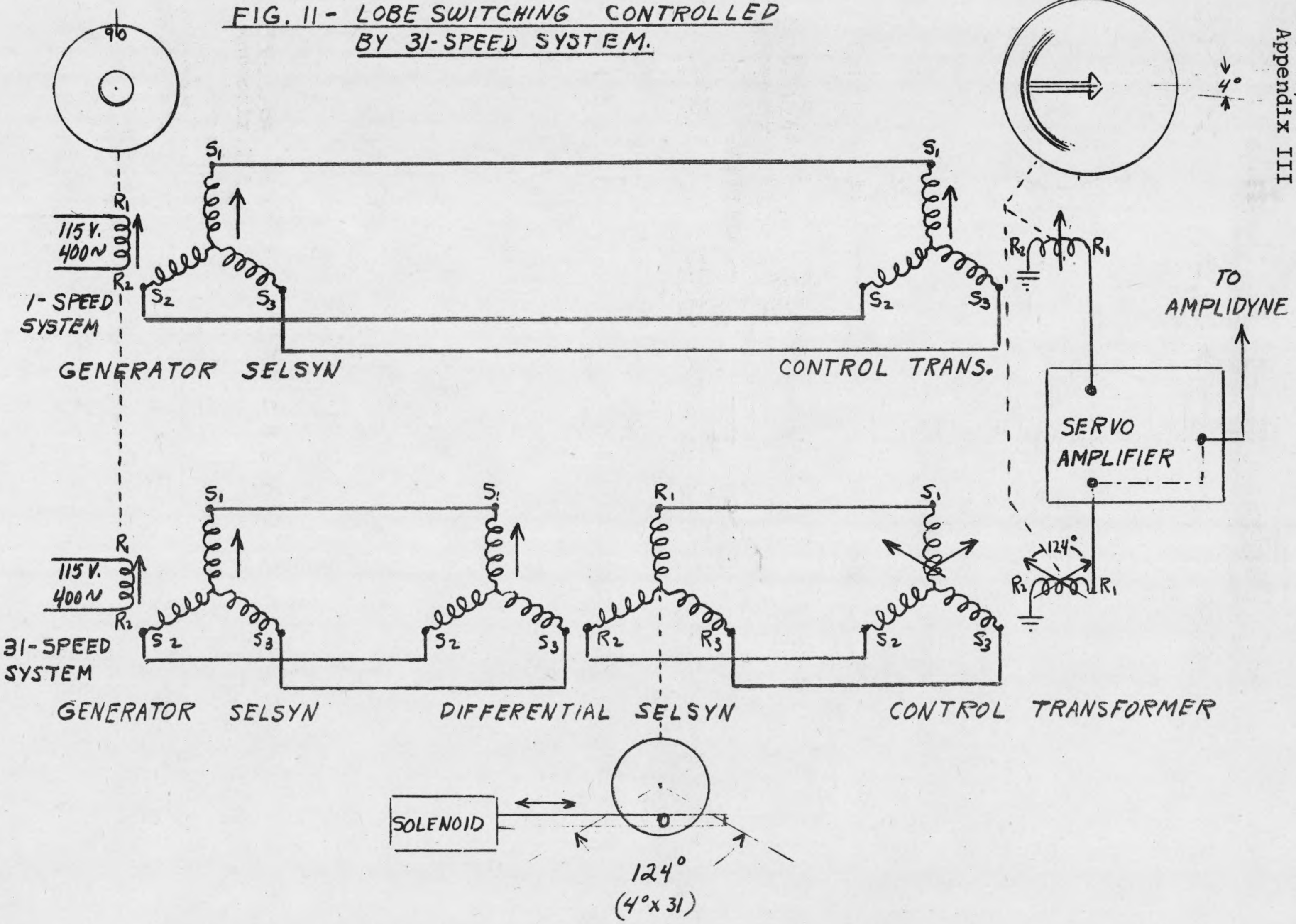
FIG. 11 - LOBE SWITCHING CONTROLLED BY 31-SPEED SYSTEM.



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each position about 1 second. Because the disalignment angle never exceeds 3 degrees, this motion can be completely controlled by a 31-speed circuit, (Figure 11) when the scan switch is thrown to lobe position.

SERVO AMPLIFIER

The servo amplifier consists of two identical amplifiers or channels either of which can be switched into the servo system by the channel switch on the antenna servo control box. For the purpose describing the amplifier operation, we will refer to channel A. (Drawing Number B4039 and Figure 12).

During the alignment process when the angle of disalignment is greater than 3 degrees, error signals or voltages enter the servo amplifier from the 1-speed and 31-speed control transformers across the primaries of T_2 and T_3 (T_2P and T_3P). The maximum voltage across either of these primaries is 57.5 volts. The maximum voltage across 1/2 of the 1-speed secondary T_2-S is 1,500 volts which occurs when the angle of disalignment is 90 degrees. The maximum voltage across the 31-speed secondary T3-S is 20 volts which occurs when the 31-speed control transformer rotor is at 90 degrees to the field produced by the 31-speed generator selsyn. The neon tubes V4 and V5 start conducting when the potential difference across them exceeds 55 volts and stop conducting when the potential difference is less than 55 volts.

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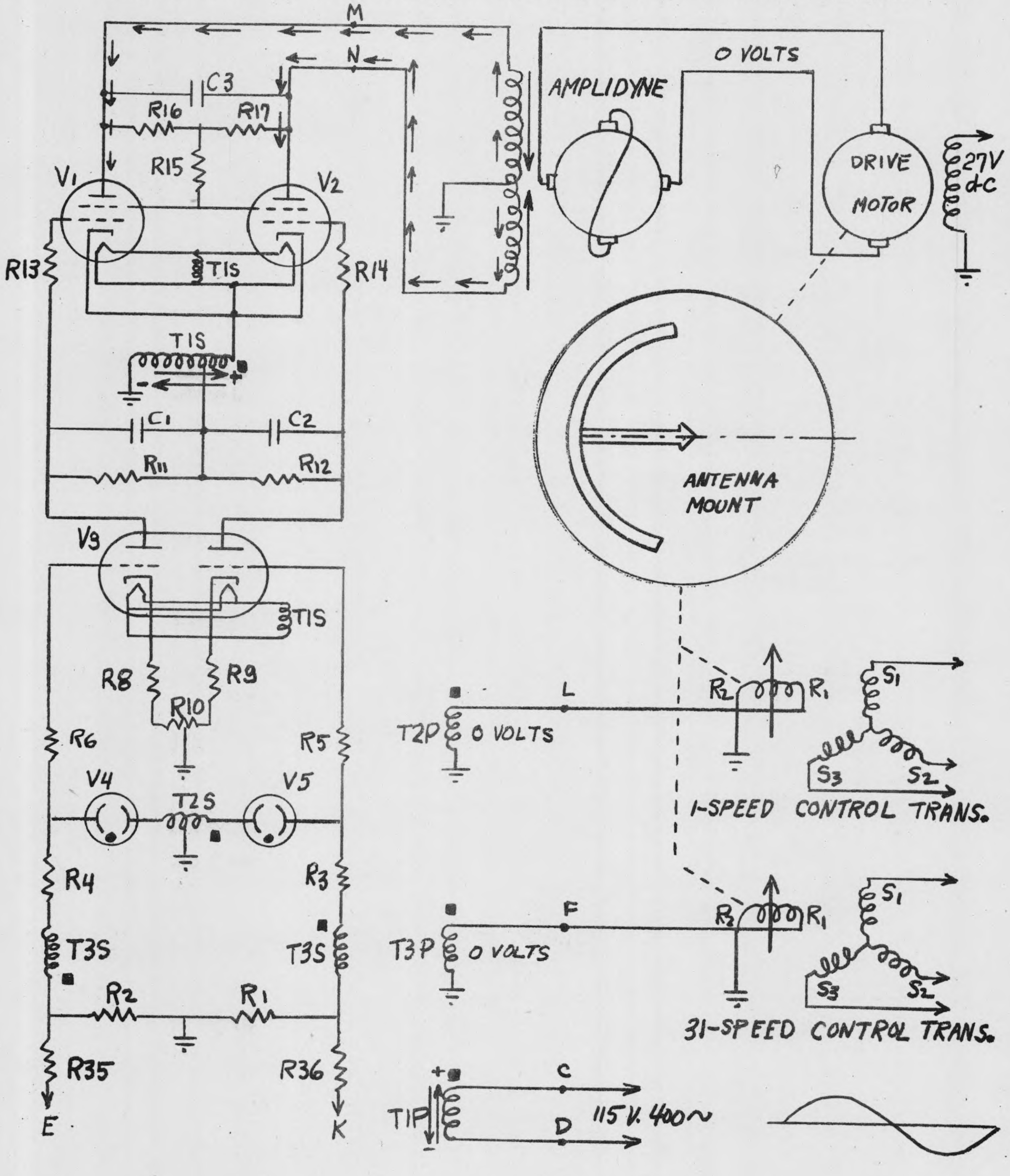
Figure 12: SERVO AMPLIFIER--CHANNEL A WITH NO ERROR SIGNAL

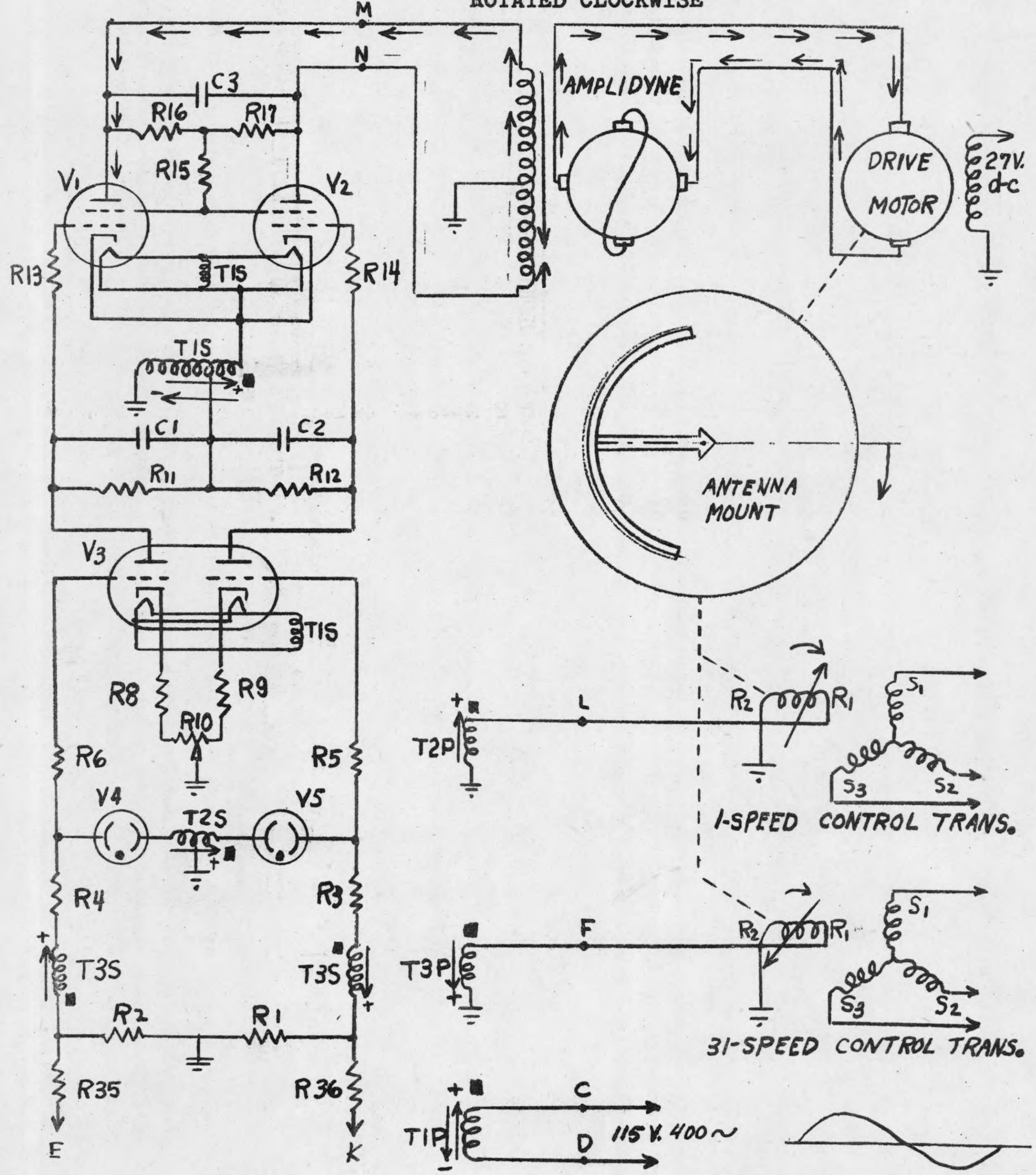


When the disalignment angle is reduced to about 3 degrees, the magnitude of voltage across 1/2 of T_2S is 1,500 sin 3 degrees 75 volts. At this angle, the 31-speed control transformer rotor is approximately 90 degrees (31 x 3) to the field causing a maximum 31-speed error signal across T_3 and a 20 volts across T_3S. Thus, for this disalignment angle, the potential difference across the tube is 75 - 20 or 55 volts. When the angle of disalignment decreases V4 and V5 cease to conduct. When the potential difference is great enough for V4 and V5 to conduct the 1-speed error signal controls the charges on the control guide of V3, but when V4 and V5 stop conducting the 31-speed signal is in control.

The error signals from the selsyns are either in phase or 180 degrees out of phase with voltage across T_1 depending on the direction the heading dial is rotated with respect to the heading of the antenna.

Figure 13 illustrates the operation of the servo amplifier when the heading dial is rotated clockwise with respect to the antenna's heading. Such motion causes the 1-speed error signal to be in phase with the voltage across T_1S. If we consider the positive half cycle, the valtage across T_1S will cause the cathodes of V_1 and V_2 to be positive with respect to their plates and the tubes will not conduct. It will also cause the plates of V3 to be positive with respect to their cathodes causing

Figure 13: OPERATION OF SERVO AMPLIFIER WHEN HEADING DIAL IS ROTATED CLOCKWISE



conduction depending upon the charges on the control grids. With the voltage across T2S inphase with the voltage across T1S and with the neon tubes V4 and V5 conducting the grid on the right half of V3 will be positive and the grid on the left half negative. This causes the right half of V3 to conduct more than the left half which creates a higher voltage drop across R12 than R11. During the negative half cycle, the plates of V3 are negative cutting V3 off and the cathodes of V1 and V2 are negative with respect to the plates causing these tubes to conduct. C2, however, maintains the voltage developed during the positive half cycle placing a negative charge on the control grid of V2 and cutting down the conduction of V2. The outputs of V1 and V2 pass through a smoothing filter network consisting of C3, R16 and R17 and on to the control field of the amplidyne. When there are no error signals from the selsyns, the outputs of V1 and V2 are identical and produce fields in the winding of the amplidyne control field that cancel each other. In this case, however, with V2 conducting much less than V1, the field in the right amplidyne control winding will be much weaker than the field on the left which produces a resultant field as shown in Figure 13. This causes the amplidyne to generate a large d-c output whose polarity is determined by the direction of this resultant field. This amplidyne output is fed to the azimuth drive motor which rotates the antenna clockwise into alignment with the heading dial.

Figure 14: OPERATION OF SERVO AMPLIFIER WHEN HEADING DIAL IS ROTATED COUNTERCLOCKWISE

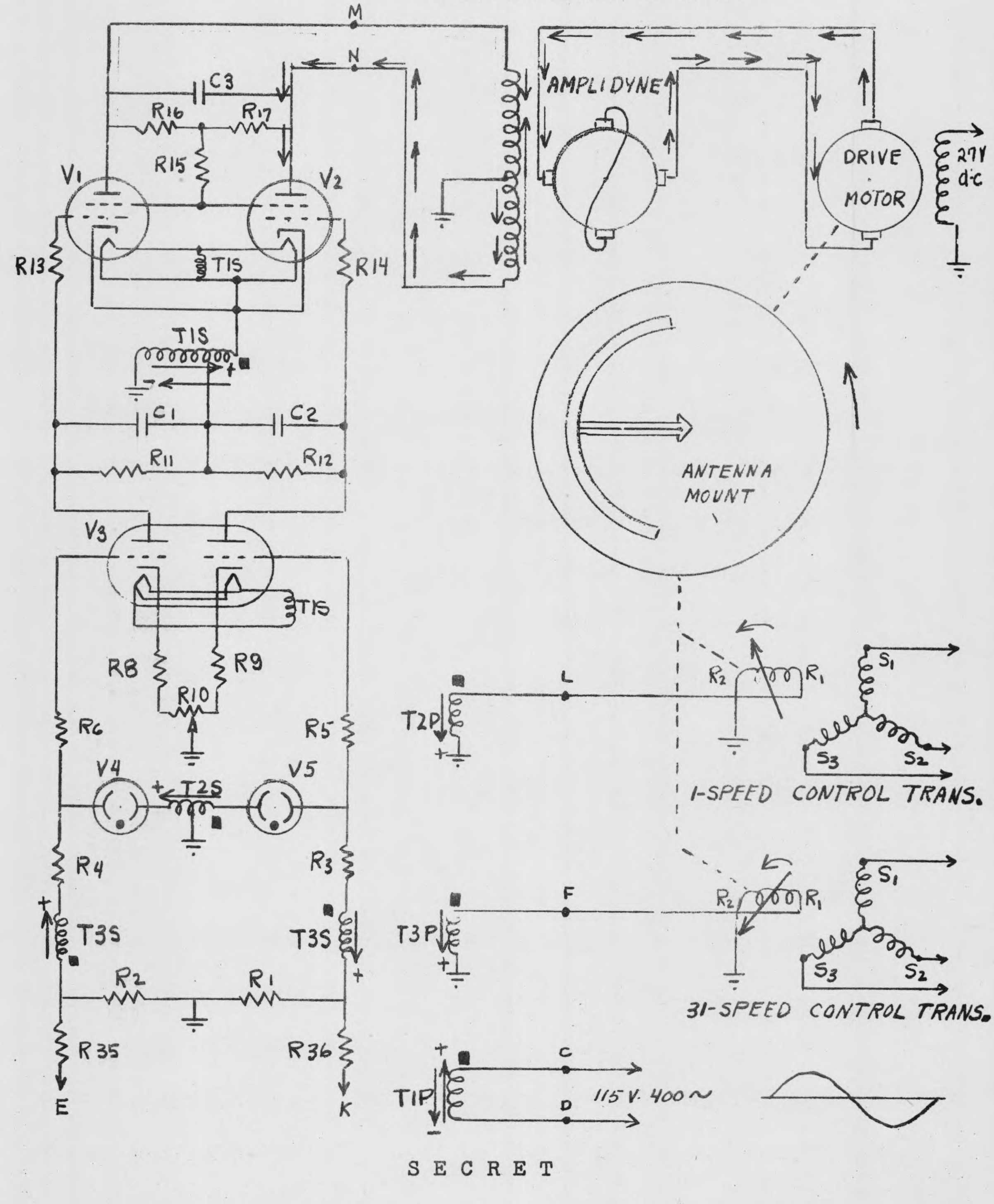


Figure 14 illustrates the operation of the amplifier when the heading dial is turned counter-clockwise. In this case, the 1-speed error signal is 180 degrees out of phase with the power input at T1. Thus, for the positive half cycle, the left half of V3 would conduct more than the right half making the voltage drop across R11 larger than the voltage drop across R12. During the negative half cycle, C1 would place a negative charge on the control grid of V1 causing the conduction of V1 to be much less than the conduction of V2. The resultant field will be in the direction shown and the output of the amplidyne will cause the azimuth drive motor to rotate the antenna counter-clockwise into alignment with the heading dial.

THE ANTI-HUNT OR STABILIZING CIRCUIT

The stabilizing circuit is used to overcome the tendency of the antenna to overshoot the position of alignment with the heading dial. For example, when there is a large angle of disalignment, the momentum of the antenna will carry it beyond the position of alignment, causing an error signal in the other direction. This causes the antenna to reverse its direction back toward alignment but again it overshoots its alignment position. This back and forth oscillation about alignment is referred to as "hunting" and could continue indefinitely. For this reason, the stabilizing circuit shown in Figure 15 is

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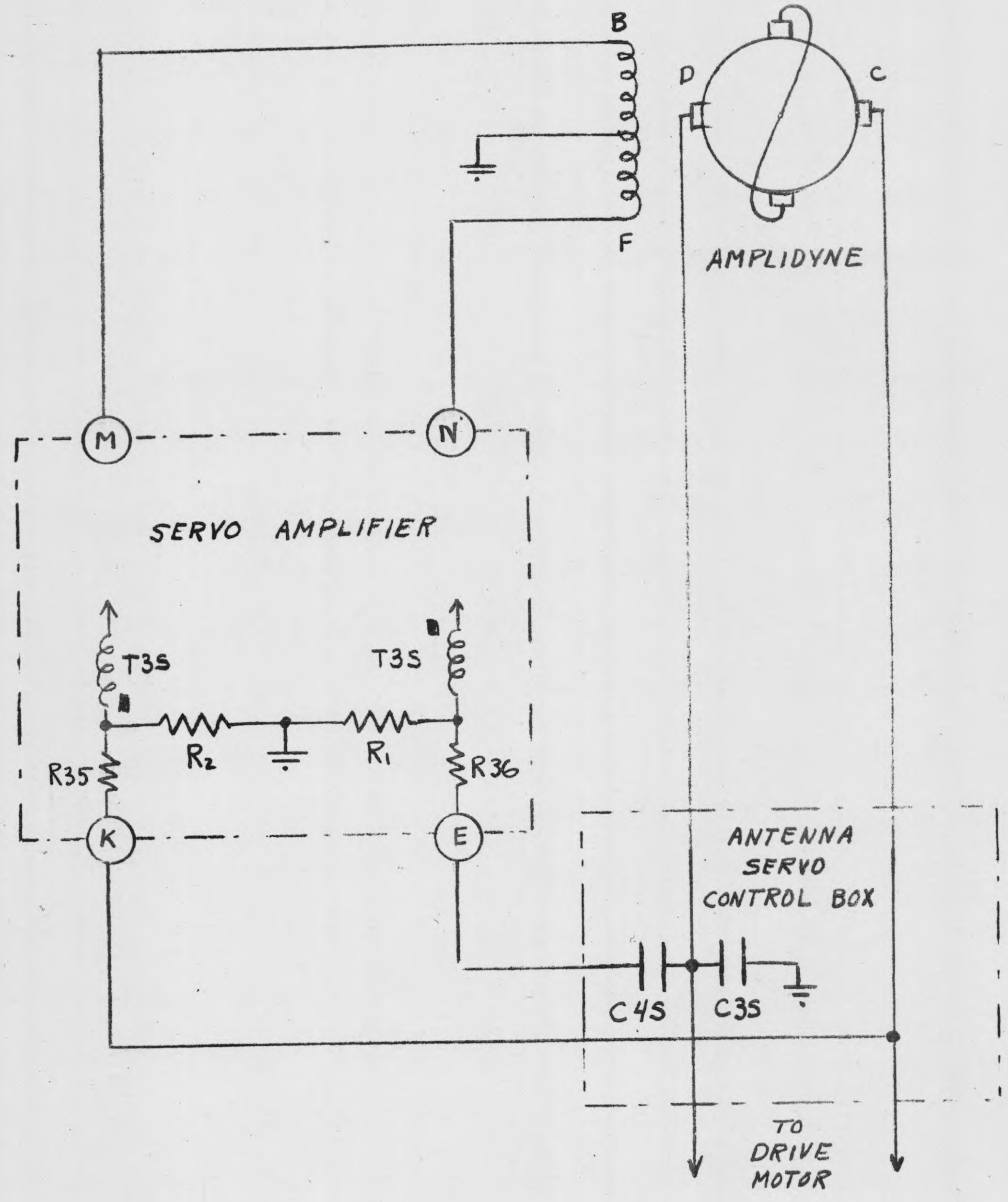
FIG. 15 - ANTI-HUNT CIRCUIT



provided. This includes R2, R1, R35, R36, C3S, and C4S in the 31-speed circuit.

During the alignment operation, the rising motor voltage across the stabilizing condenser Number C4S and resistors R1 and R2 causes the condenser to take a charging current through the resistors in the direction shown by the arrows. This current lasts only as long as the voltage is rising. While it lasts, it produces a voltage drop across each resistor that opposes the signal voltage in the 31-speed circuit during the operating half cycle of V3. This effect gives the capacitor a charge that is used later.

While the heading dial and antenna are moving at the same speed (tracking), the motor voltage is constant, so the capacitor is neither charging nor discharging and only the disalignment signal is in control.

When the heading dial slows or stops, the antenna is driven to decrease the disalignment and reduce the signal voltage. This reduces the motor voltage. The stabilizing condenser C4S now discharges through R1 and R2 causing voltages that aid the reducing error signal. This causes the antenna to move more rapidly to the position of alignment than it otherwise would. When the momentum of the antenna carries it beyond the position of alignment, C4S still continues to discharge through R1 and R2 which produces voltages that now oppose the reversed 31-speed error signals. As a result, the antenna moves back into alignment slowly and does not overshoot.

It would be possible to prevent hunting without condenser C4S, but there would then be an anti-hunt signal across R1 and R2 wherever there was an amplidyne output. If the amplidyne output were constant, as in tracking, there would be a constant error in the position of the antenna because of this constant error introduced to the servo through the anti-hunt system. C4S, therefore, permits an anti-hunt signal only when the amplidyne output is changing. It should be noted that condenser C4S will charge or discharge whenever there is a change in the amplidyne output. If there were a cyclic variation in the amplidyne output (an a-c component), this would appear across R1 and R2 because of the charging and discharging of C4S and feed back to the amplidyne through the servo.

This is prevented by connected condenser C3S between the line from the amplidyne to C4S and ground. Condenser C3S by-passes the cyclic fluctuations in the amplidyne output to ground. Only the average d-c value affects C4S.

BASIC ELEMENTS OF ANTENNA SERVO CONTROL BOX

1. 1-Speed Heading Dial Assembly (3 dials)

   a. Heading Marker--plastic dial with red line which is used to remember heading of sector during sector scanning. It can be rotated with respect to the heading dial (b) and clamped to indicate any heading.

   b. 1-Speed Heading Dial--aluminum dial calibrated in 36 10-degree divisions and can be read to the nearest 10-degree mark under the black hairline. Can be made to turn freely with respect to its shaft and be clamped in any heading position when orienting the truck. Dial rotates one revolution for one revolution of the antenna.

   c. Sector Scan Dial--aluminum dial with red line which oscillates with antenna during sector scanning and indicates the position of the antenna in the sector relative to the center of the sector which is represented by the hairline.

2. 36-Speed Heading Dial--aluminum dial calibrated in 100 divisions each representing 0.1 degree. To be read with 1-speed heading dial under hair line for readings to the nearest 0.1 degree. Can be rotated freely with respect to its shaft and be clamped in any heading position when orienting the truck. Rotates 36 revolution for one revolution of the antenna.

3. Sector Scan Angle Dial--aluminum dial calibrated in 120 divisions representing 120 degrees. Indicates width of sector that antenna scans and is read under black hairline. Can be rotated freely with respect to its shaft for correct angle readings.

4. 31-Speed Knob--rotates 31 revolutions for one revolution of the antenna.

5. Tilt Indicator--indicates approximate position of antenna in elevation.

6. Search Direction Switch (DPDT)--changes direction of rotation of antenna in automatic search.

7. Power Switch (SPST)--switches on and off power entering antenna servo control box.

8. Antenna Switch (SPST)--operates relay which opens or closes field and armature circuits of antenna azimuth drive motor.

9. Search Switch (DPDT)--switches on and off automatic search. Must be turned off before antenna can be manually controlled.

10. Scan Switch (SPDT)--three position switch. Can switch from a neutral position to lobe switch or to sector scan.

11. Beam Switch (SPST)--controls beam switch motor which rotates antenna dish 90 degrees from a position generating a 10 degree beam to a position generating a 3-degree beam.

12. Tilt Switch (SPDT)--operates tilt motor which elevates or depresses antenna.

13. Gear trains for 1-speed and 31-speed heading and sector scan selsyns.

14. Lobe Switch control unit.

15. Lobe Switch 31-speed differential selsyn.

16. Relay and condenser panel.

17. Condenser box for power factor correction condensers.

18. Channel Switch--switches servo amplifiers.

19. Panel light switch.

20. Left horizontal positioning potentiometer for TS-34.

21. Right horizontal positioning potentiometer for TS-34.

22. Search speed rheostat.

23. Sector Scan speed rheostat.

24. Lobe Switch speed rheostat.

25. Choke for d-c supply to TS-34.

26. 1-Speed Selsyn Switch (SPST)--opens or closes 1-speed selsyn circuit.

27. 60 Cycle Switch (SPST)

28. 31-Speed Selsyn Switch (SPST)--opens or closes 31-speed selsyn circuit.

29. Lobe Switch Terminal Strip.

30. Lobe Switch cam switch

31. Lobe Switch solenoid plunger.

32. Lobe Switch solenoid.

33. Lobe Switch motor.

34. Sector Scan motor.

35. Sector Scan terminal strip.

36. 31-speed Sector Scan Differential Selsyn.

37. 1-speed Sector Scan Differential Selsyn.

38. Search terminal strip.

39. 1-speed generator selsyn.

40. Indicator Selsyn--feeds azimuth heading information to plotting table.

41. Field resistors (33 ohm) for search, sector scan, and lobe switch motors.

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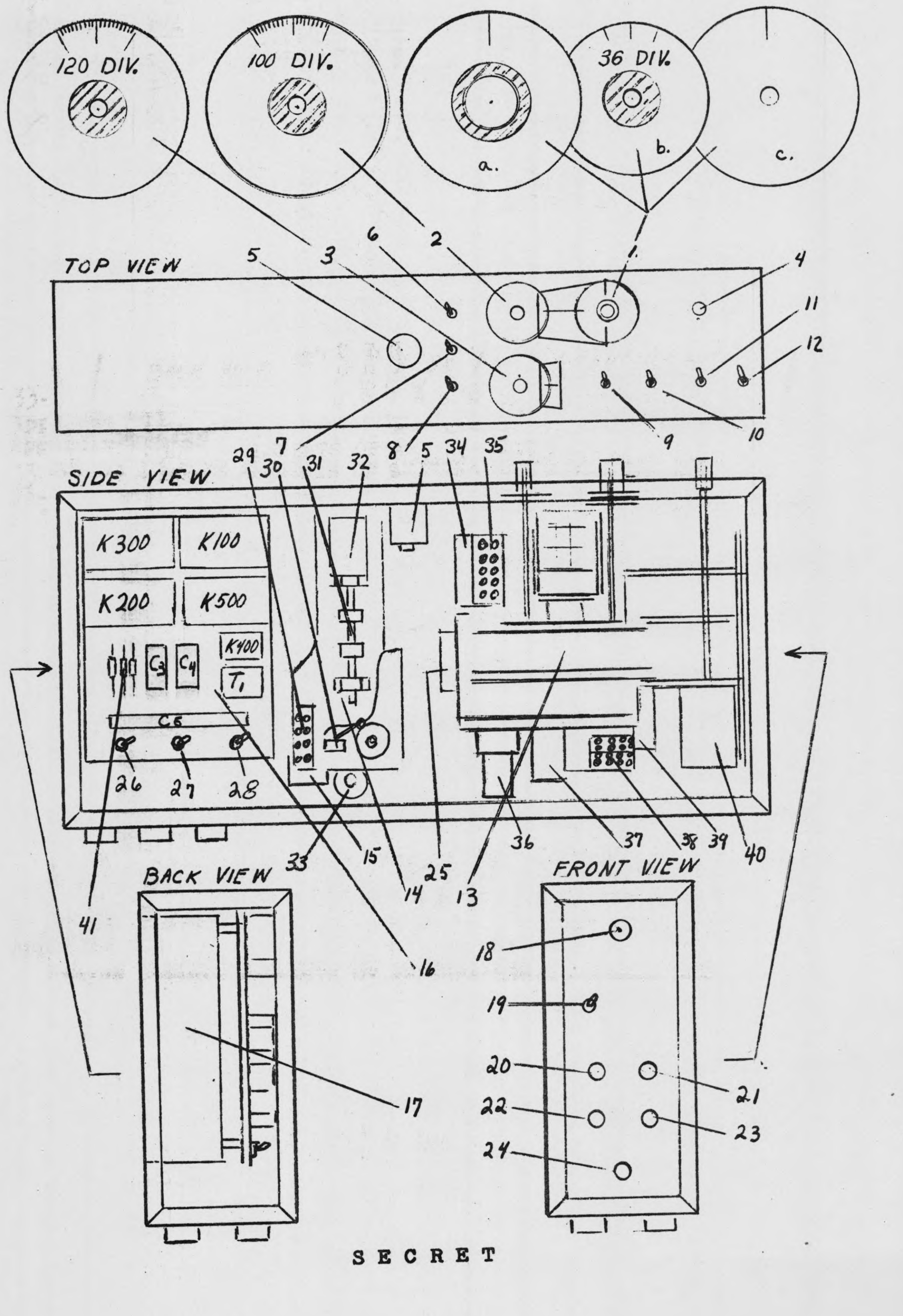
FIG. 16 - BASIC ELEMENTS OF ANTENNA SERVO CONTROL BOX



MECHANICAL SYSTEMS

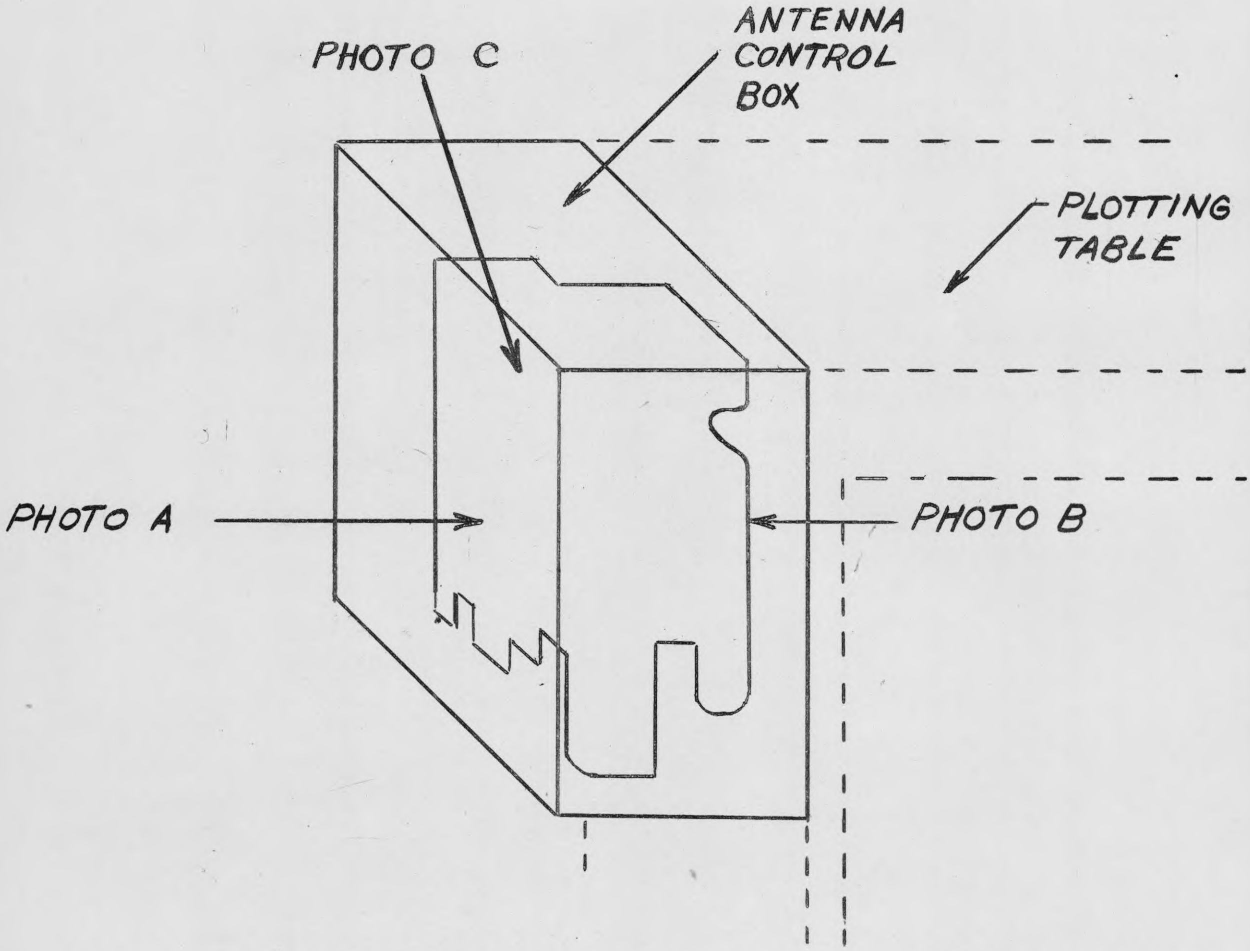


Figure 17: PHOTOGRAPHIC VIEWS OF THE SELSYN CONTROL GEAR SYSTEM

In the following discussion of the mechanical systems used to control the heading generator selsyns and the sector scan differential selsyns, reference will be made to Photographs A, B, and C (Figure 17), and to Figures 18, 19, and 20. Photograph A shows a head on view of the left side of the selsyn gear system; Photograph B, the right side of the system; and Photograph C, an oblique view of the sector scan control mechanism.

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LOCATION OF COMPONENTS (PHOTOGRAPHS A, B, C)

1. 31-Speed sector scan differential selsyn
2. 1-Speed sector scan differential selsyn
3. Search motor assembly
4. Search terminal strip
5. 96 Tooth gear on 1-speed sector scan differential selsyn shaft
6. 96 Tooth gear on sector scan transmission shaft
7. 1-Speed generator selsyn (heading)
8. 60 Cycle heading indicator selsyn--feeds azimuth heading information to plotting table
9. Sector scan transmission shaft
10. Sector scan control mechanism
11. Sector scan terminal strip
12. Sector scan motor
13. Sector scan power gear train
14. Sector scan selsyn gear train--1-speed to 31-speed
15. 31-Speed generator selsyn (heading)
16. Gear train for heading generator selsyns and search motor power transmission--31-speed to 1-speed to 36-speed
17. Search motor
18. 31-Speed shaft
19. 31-Speed knob
20. 1-Speed shaft
21. 96 Tooth gear attached to sector scan sleeve
22. Sector scan sleeve--rotates freely on 1-speed shaft
23. Sector scan dial--attached to sector scan sleeve

24. 1-Speed heading dial

25. Plastic heading marker dial

26. 1-Speed heading knob

27. 36-Speed knob

28. 36-Speed shaft

29. 36-Speed heading dial

30. Sector scan angle knob

31. Sector scan angle dial

32. Idler between 96 tooth gear on 1-speed heading shaft and 16 tooth gear on heading indicator selsyn rotor

33. 16 Tooth gear on heading indicator selsyn rotor

34. Phosphor bronze ribon spring that holds sector scan angle shaft up in locked position

35. Sector scan angle shaft lock

36. Sector scan angle shaft

37. Sector scan limit differential gear assembly

38. 96 Tooth gear whose spoke acts as a mechanical limit

39. Sector scan tongue--engages sector scan ratchet

40. 96 Tooth gear attached to sector scan transmission shaft

41. Sector scan ratchet

42. Tension spring--tends to disengage tongue from ratchet

43. Cradle post--transmits force received from mechanical limits to engage or disengage tongue

44. Mechanical limit

45. Idler between 96 tooth gear on sector scan transmission shaft and 96 tooth gear attached to sector scan sleeve

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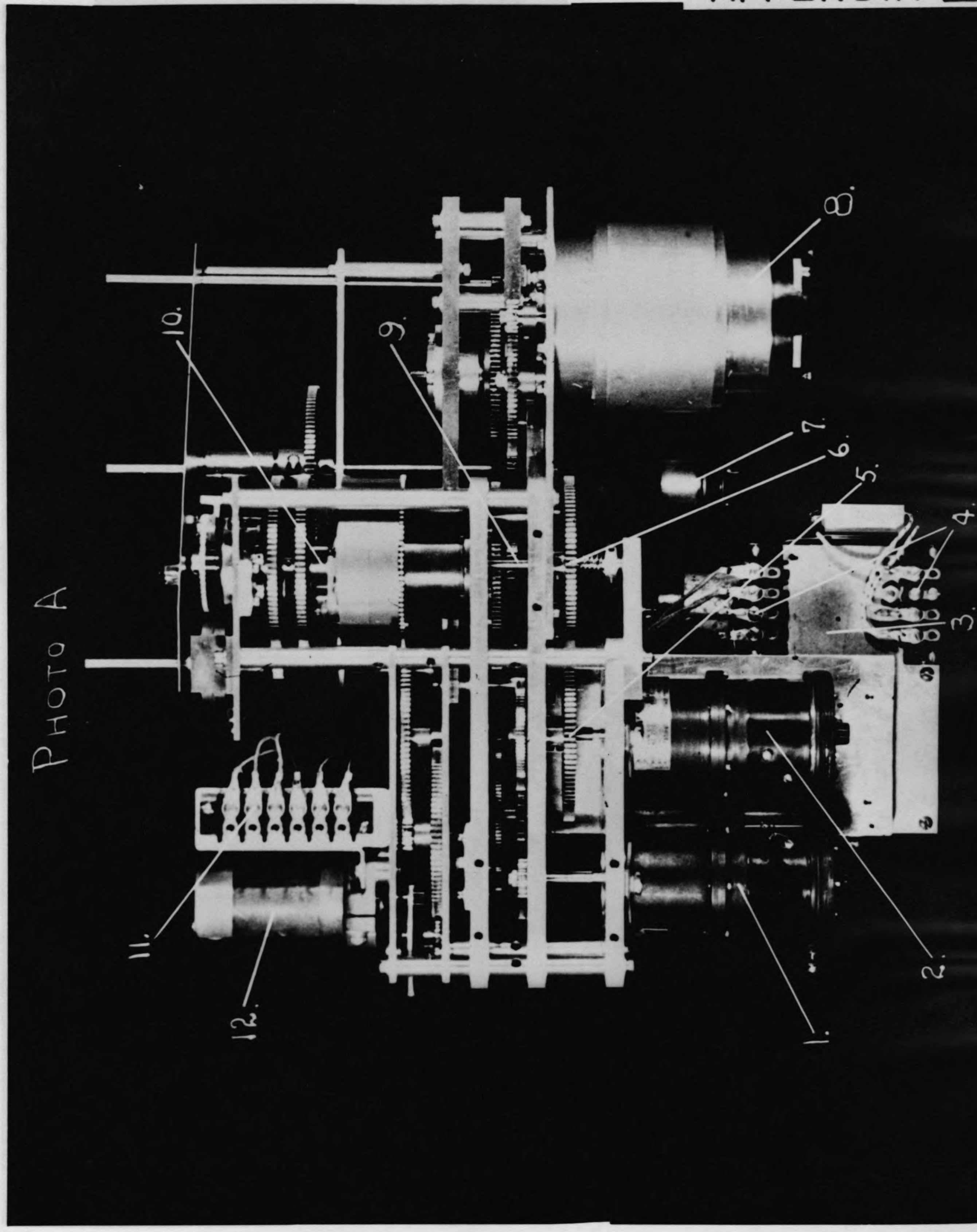

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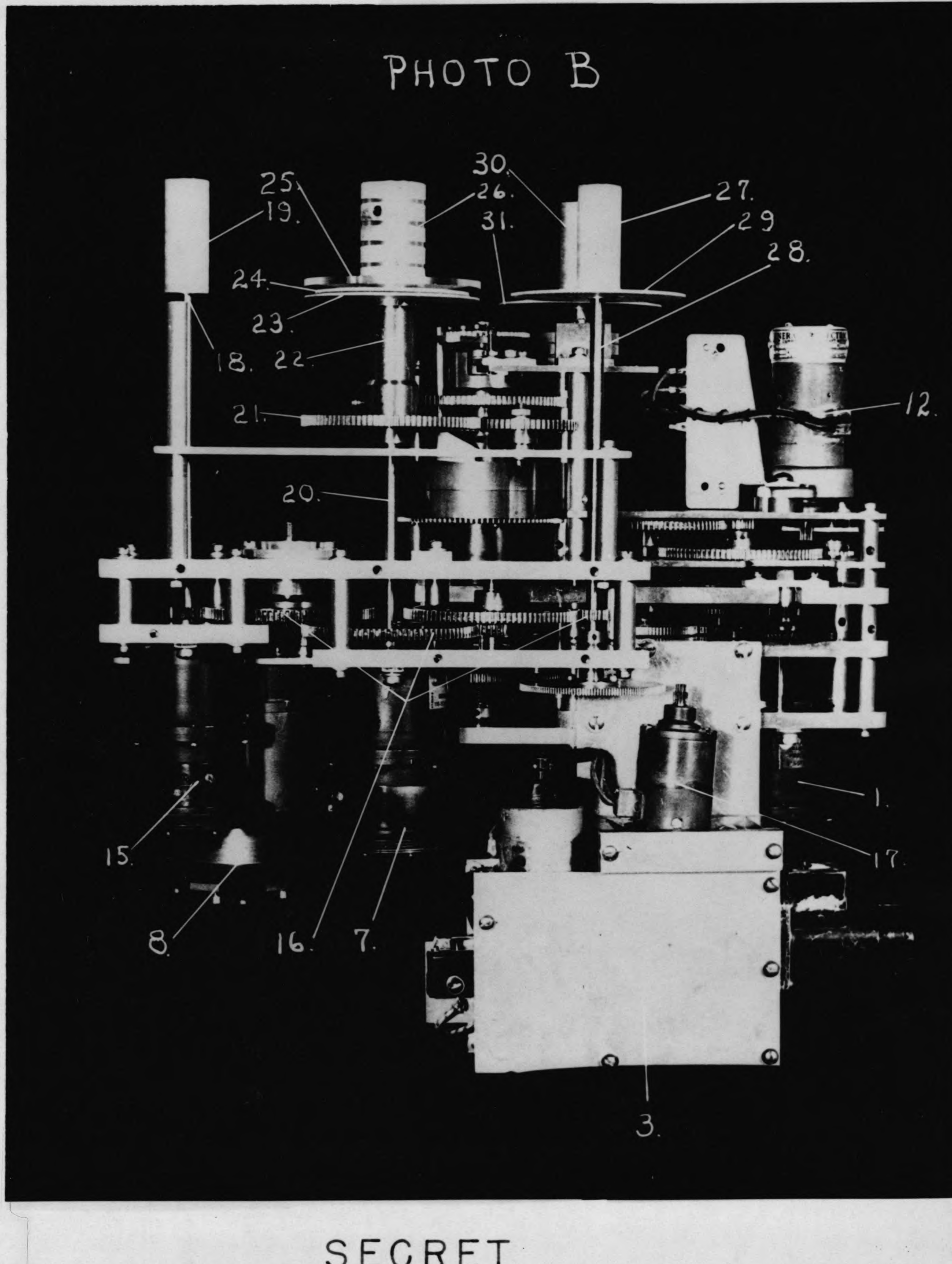
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MECHANICAL OPERATIONS

SEARCH

When the search switch is turned on (Figure 18 and Photograph B) solenoid A is energized which causes the spring loaded solenoid rod to rotate the search motor about its pivit and engage the selsyn gear train. (16) This causes the spring loaded rod of solenoid B to be released which locks the motor in this engaged position and also throws the micro switch which deenergizes solenoid A. At the same instant, a d-c voltage is placed across the armature of the search motor with a polarity determined by the position of the search direction switch, and across the field of the motor causing it to turn. Thus, the motor starts rotating and engages the selsyn gear train in one operation.

If considerable resistance is placed in series with the armature by the speed rehostat before the search switch is turned on, it is possible that the motor will merely engage the gear train but not rotate. Under this condition, heading gear train is locked and cannot be turned manually. For this reason, it is important to see that the search switch is in the off position before manually operating the heading dials.

When the search motor is engaged and rotating (Photograph B), this motion is transmitted through the heading gear train (16) to the rotors of the 1-speed generator selsyn (7), the 31-speed generator selsyn (15),

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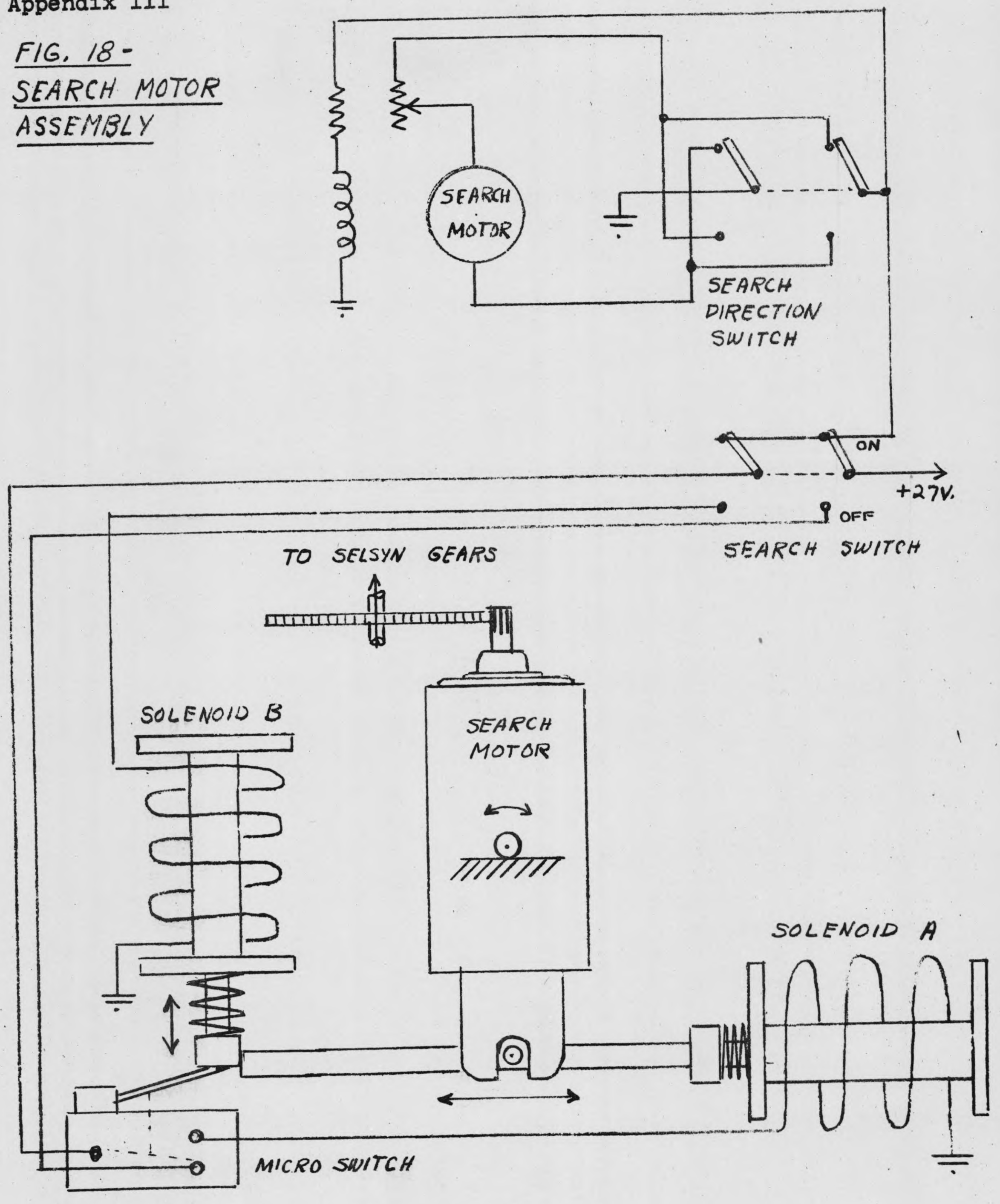
FIG. 18 - SEARCH MOTOR ASSEMBLY



and the indicator selsyn (8). The generator selsyn sends out continuous errors signals which pass through servo system, causing the antenna to follow this motion. The indicator selsyn sends error signals to the azimuth selsyn motor in the plotting table which causes the plotting table arm to follow the antenna. During this operation, the heading dials (24 and 29) display the continuous change of heading of the antenna.

When the search switch is turned off (Figure 18), d-c power to the search motor is cut off and the motor stops. At the same time, solenoid B is energized causing its spring loaded rod to move into the solenoid releasing the spring loaded rod of solenoid A. This rod flies out of solenoid A and causes the search motor to rotate on its pivot and disengage the selsyn gear train. The motion of the rod of solenoid B also throws the micro switch which deenergizes solenoid B. Thus, it can be seen that solenoids A and B are energized only during the times the search motor is engaging or disengaging.

Manual search produces the same effect as does automatic search except that the motion is now transmitted to the selsyn gear train (16) from any one of the three heading knobs (19, 26, 27).

SECTOR SCANNING

Reference is made to Photographs A and C and to Figure 19. The sector scanning motion is generated in the

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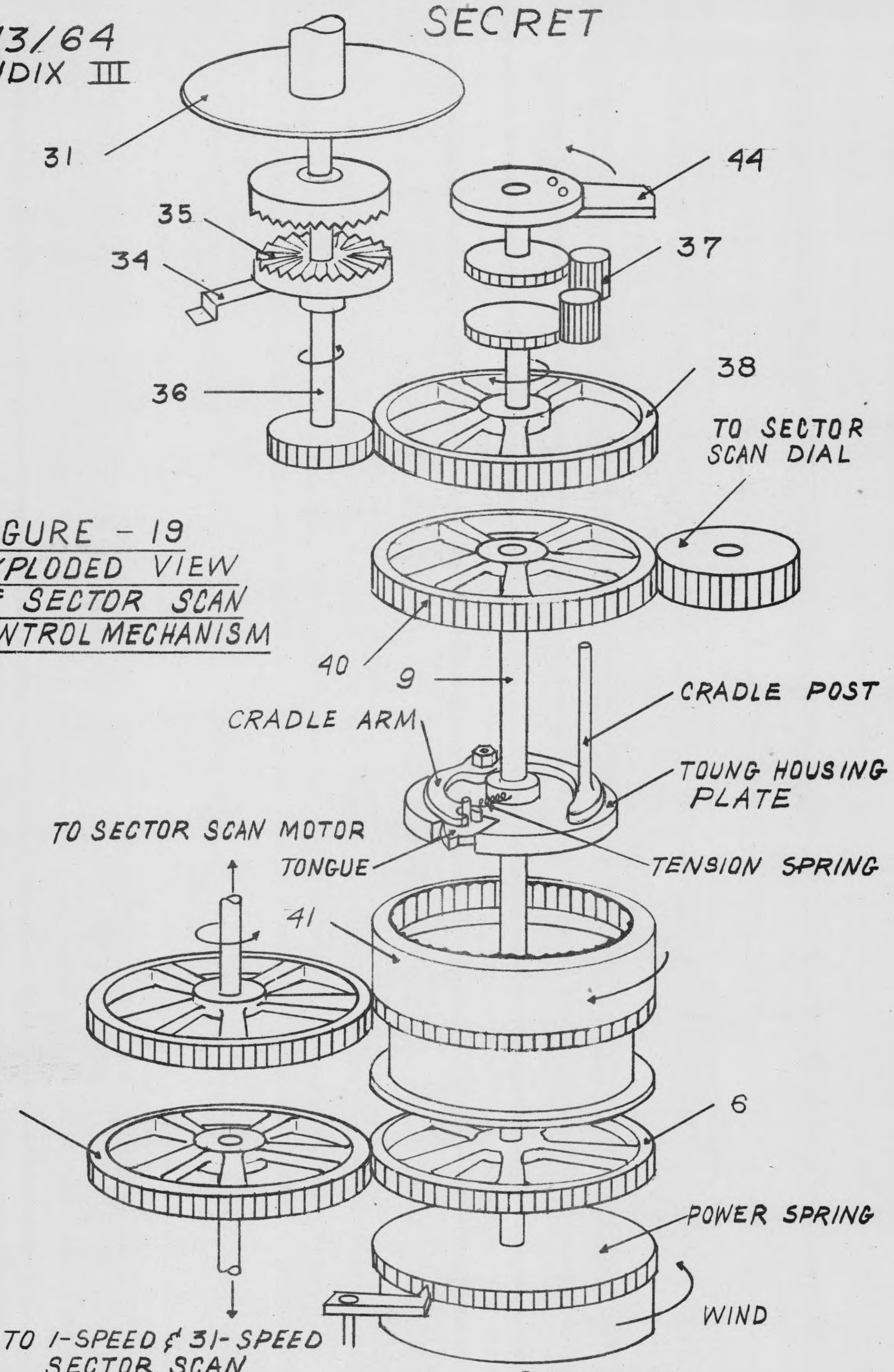

FIGURE - 19
EXPLODED VIEW OF SECTOR SCAN CONTROL MECHANISM

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sector scan control mechanism and is transmitted to the sector scan differential selsyns which send error signals through the servo system causing the antenna to reproduce this motion. The sector scan control mechanism (Photograph C and Figure 19) is a device in which a torsionally spring loaded shaft is made to rotate slowly clockwise through an angle governed by adjustable mechanical limits, fly back rapidly through the same angle and then repeat the process.

The sector scan motor provides the power for this mechanism and transmits it over the sector scan power gear train (13) to the sector scan ratchet (41). This ratchet rotates clockwise at about 4°/sec. on a 2-inch bearing during sector scanning. The mechanical limits in this mechanism are the spoke on a 96 tooth gear (38) and a small plate (44). Both are attached to a differential gear assembly (37) which causes the limits to rotate in opposite directions with respect to each other.

The sector scan transmission shaft (9) is torsionally spring loaded at one end by means of a power spring that can be wound in a counter-clockwise direction for adjustment of initial torque. (In this discussion, all rotations will be considered as being observed from the top view.) The tongue housing plate is mounted on this shaft and rotates with this shaft inside the sector scan ratchet. (Figure 19) The tongue can be made to move in or out of this housing plate engaging or disengaging the ratchet. The position of the tongue is determined by cradle arm which swings about its pivot when a force is applied to the cradle post. A weak tension spring tends to keep the tongue in the tongue housing plate when it is not engaged with the ratchet.

Attached to the top of the sector scan transmission shaft is a 96 tooth gear (40) which transmits the sector scan motion through an idler (45) to the sector scan dial (23). Since there is no relative motion between this gear and the tongue housing plate, the cradle post can pass between two of the spokes and be moved back and forth with the cradle arm through the short travel of the tongue.

Directly above this gear on the same center line are mounted the mechanical limits of this mechanism. Both the spoke of the 96 tooth gear (38) and the small plate (44) can exert forces on the cradle post when contact is made due to the rotation of the sector scan transmission shaft. The force imparted to the cradle post by the spoke of the 96 tooth gear (38) due to a clockwise rotation of the sector scan transmission shaft causes the cradle arm to rotate about its pivot counter-clockwise disengaging the tongue from the ratchet. The force imparted to the cradle post by the other mechanical limit (44) when the sector scan transmission shaft is rotated counter-clockwise causes the cradle arm to move clockwise about its pivot engaging the tongue with the ratchet.

The position of these mechanical limits is determined by the sector scan angle shaft (36) on which there is mounted a 16 tooth gear that engages the 96 tooth gear (38). One revolution of this shaft causes the 96 tooth gear and its spoke that serves as a mechanical limit to move through 60 degrees. At the same time, the differential gear assembly causes the other mechanical limit to rotate 60 degrees in the opposite direction. Thus, one revolution of the sector scan angle shaft causes the mechanical limits to move 120 degrees with respect to each other. The sector scan angle dial (31) mounted on this shaft is calibrated to read 120 degrees for one revolution, and therefore, displays the angle between the mechanical limits which becomes the angle through which the mechanism sector scans. In order for these limits to remain in fixed positions relative to each other when imparting forces to the cradle post, it is necessary to hold the sector scan angle shaft in each position or setting. This is accomplished by the sector scan angle shaft lock (35) which is held in a locked position by a phosphor bronze ribbon spring (34). Thus, before the shaft can be rotated to change the sector angle, it is necessary to push down on it and unlock it.

We may now briefly describe the overall operation of the mechanism. Assume that the sector scan angle dial is set at 60 degrees. This means that each limit has been rotated in opposite directions 30 degrees from the center line. Let us further assume that the power spring has been wound up providing an initial torsional load on the transmission shaft (9) and the tongue is engaged with the rotating ratchet. This results in a slow clockwise rotation of the transmission shaft and of the tongue housing plate and cradle post, and an increase in the torsional load as the spring winds. When the cradle post comes in contact with the spoke on the 96 tooth gear (38), the spoke exerts a force on the cradle post causing the cradle to rotate about its pivot counter-clockwise disengaging the tongue from the ratchet. As soon as the ratchet is disengaged, the spring loaded transmission shaft flies back rapidly counter-clockwise through 60 degrees until the post comes in contact with the other mechanical limit. (44) The force exerted on the post by this limit causes the cradle arm to rotate about its pivot clockwise engaging the ratchet. The transmission shaft then resumes its slow clockwise motion. During the fly back, the weak tension spring keeps the tongue from engaging the ratchet until the cradle post comes in contact with the mechanical limit. During the clockwise scan, the tongue remains engaged with the ratchet because the frictional force between the

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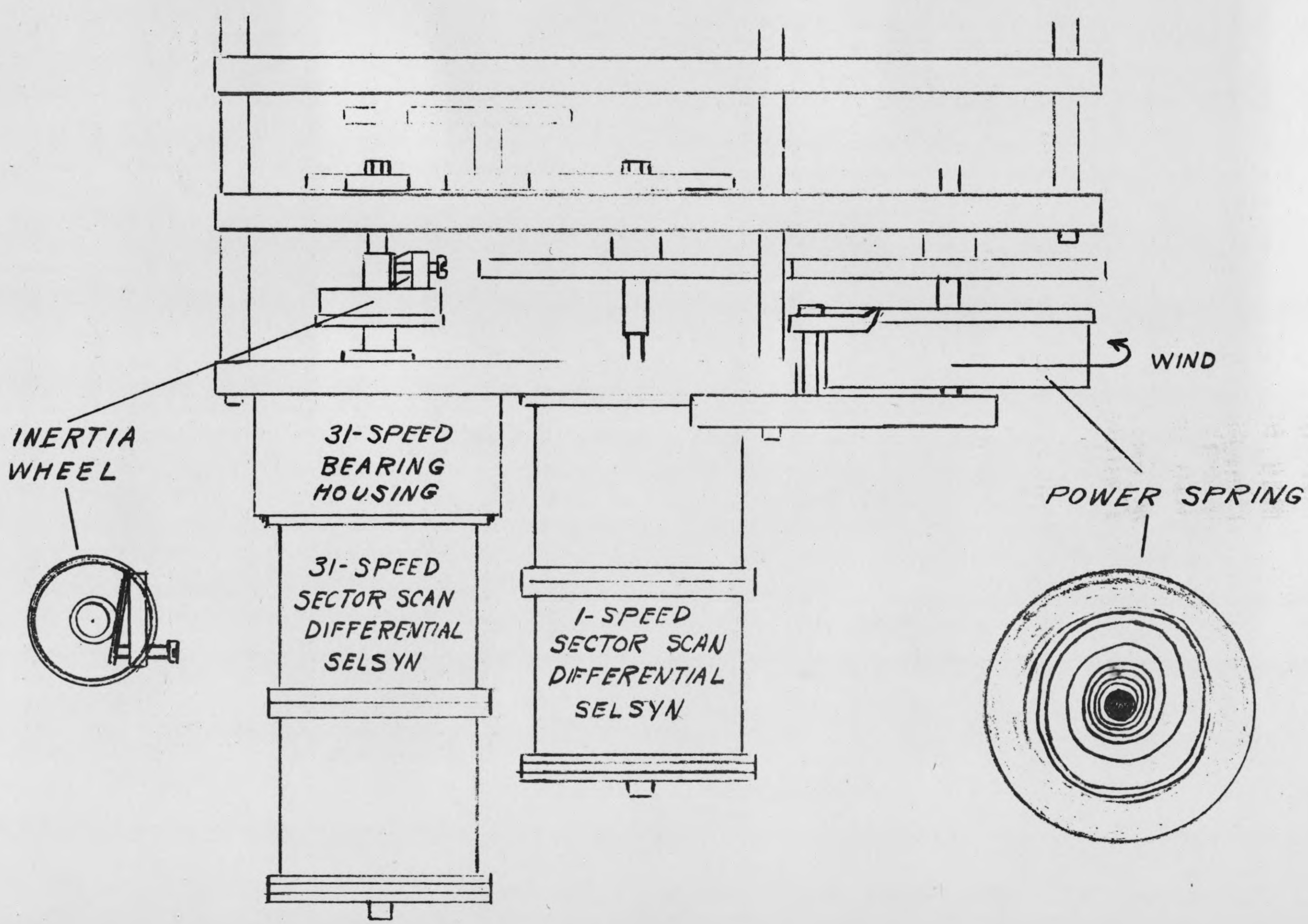
FIG. 20 - MODIFICATIONS IN SECTOR SCAN GEAR SYSTEM



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tongue and the ratchet is much greater than the force produced by the tension spring.

MODIFICATIONS IN THE SECTOR SCAN GEAR SYSTEM

Since Photographs A, B, and C were taken, certain modifications were made in the sector scan gear system. (Figure 20) The power spring discussed above was added, and an inertia wheel was placed on the rotor shaft of the 31-speed differential selsyn to mechanically damp the oscillations set up by the power spring. Also, a 31-speed bearing and bearing housing was added to insure smooth rotation of the 31-speed rotor. The following procedure is to be used in adjusting the inertia wheel.

The sector scan mechanism is put into operation and the power spring is wound to provide an adequate initial torsional load. The friction between the inertia wheel and the 31-speed shaft is then gradually increased by turning the small set screw until the oscillations set up by the power spring are reduced to a minimum.

PROCEDURE FOR REMOVING SELSYN GEAR SYSTEM FROM ANTENNA CONTROL BOX

If it becomes necessary to remove the selsyn gear system from the antenna servo control box, the following procedure should be used:

1. Remove selsyn caps and wiring from terminal strips. These wires are numbered and reference should be made to Figure 21 which shows their correct location.

2. Loosen A-N connector plate on bottom of control box and remove lower left 28-inch angle aluminum section.

3. Remove front panel from selsyn gear system

4. Remove 6 screws holding selsyn gear system to right side of box. Selsyn gear system can now be removed.

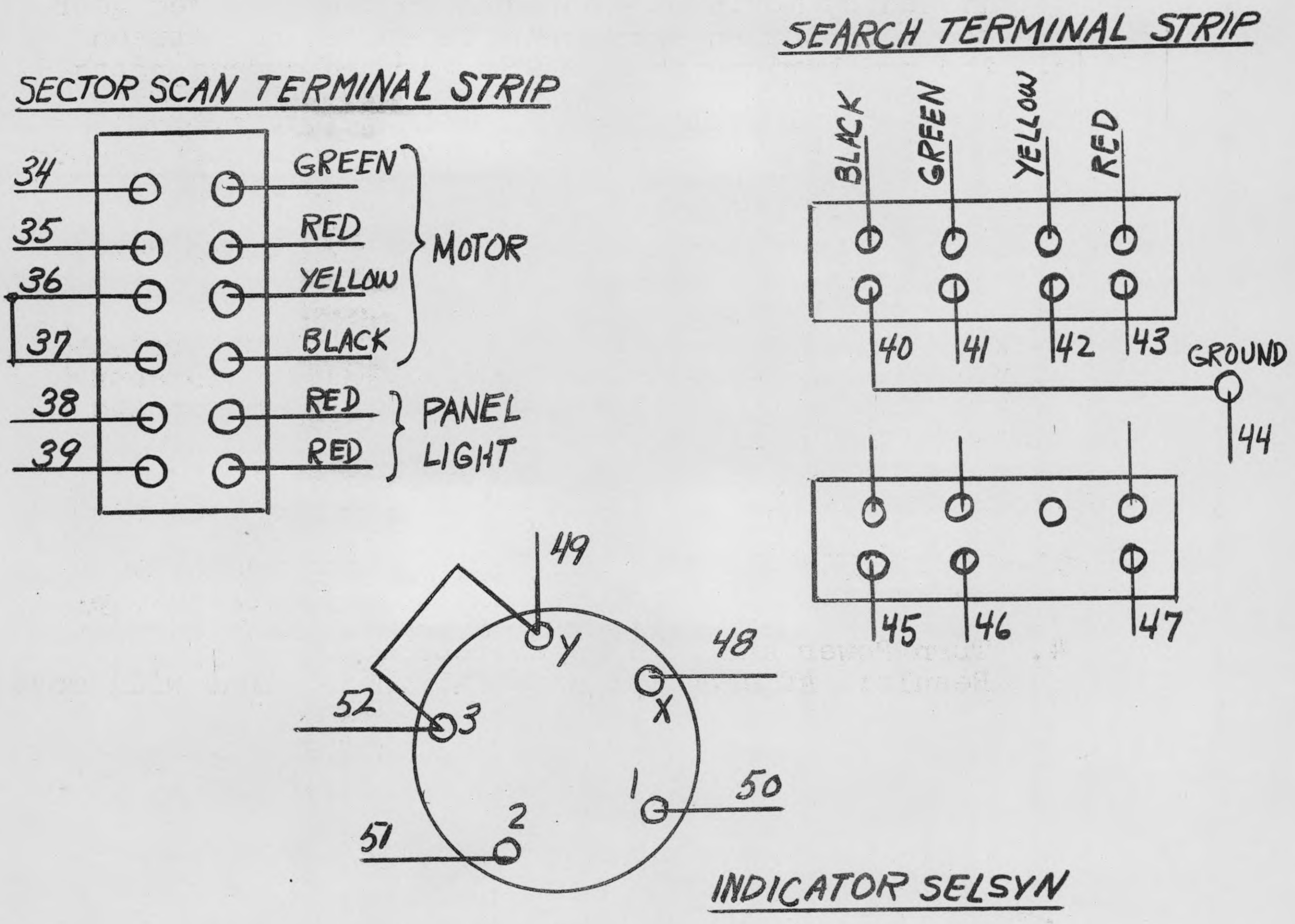

Figure 21: TERMINAL STRIP WIRING IN SELSYN GEAR SYSTEM

ZEROING PROCEDURE

A. Zeroing Generator Selsyns (Model 2J1F1)

1. Turn 60 cycle switch off. This is done to protect operator from "hot" leads on 60 cycle indicator selsyn during the zeroing procedure.

2. Turn Power and Antenna switches off, Scan switch to neutral position, and Search switch off.

3. Loosen stator clamp screws on the 31-speed generator selsyn. It is not necessary to touch the 1-speed generator selsyn during the zeroing procedure.

4. Turn Power and Antenna switches on.
   Result: After a few seconds, the antenna will move to a heading determined by the position of the 1-speed generator rotor and will probably hunt due to a disalignment between the 1-speed generator and the 31-speed generator.

5. Rotate the 31-speed generator selsyn stator until hunting ceases.

6. With one hand holding the 31-speed stator, rotate the heading dial and observe whether the antenna follows smoothly. If hunting occurs, adjust the position of the 31-speed stator.

7. Clamp 31-speed generator selsyn stator.

8. Rotate heading dial until the antenna stops on the antenna zero reference mark. This is accomplished by moving the antenna so that the red gear tooth on the antenna mount is above and between the red bars on the antenna zero reference plate.

9. Unlock 1-speed and 36-speed dials and turn until 0 is read on both heading dials under the hairline.

10. Lock dials in this zero position.

B. Zeroing Sector Scan Differential Selsyns

1. Turn Power and Antenna switches on, 60 cycle off, Scan switch in neutral position, and Search off.

2. Turn 400 cycle power switch located on power distribution box off.

3. Turn Scan switch to Sector position.

4. Set Sector Scan Angle Dial to a convenient angle--60-80 degrees.

5. Observe motion of red line on Sector Scan Dial under 1-speed heading dial. This line represents the antenna heading during sector scan. Turn Scan switch to neutral position, stopping this red line under the hairline.

6. Remove field and armature leads of Sector Scan motor (red and green) on sector scan terminal strip.

7. Turn 400 cycle power on.

8. Turn heading dial until antenna moves into zero reference position.

9. Loosen stator clamps on both 1-speed and 31-speed sector scan differential selsyns.

10. Turn Scan switch to Sector position.
Result: Antenna will move to a heading determined by the position of the 1-speed sector scan differential selsyn rotor and will probably hunt due to disalignment with the 31-speed differential selsyn.

11. Rotate 1-speed stator until antenna moves back into the zero reference position and rotate the 31-speed stator until antenna stops hunting.

12. Clamp 1-speed stator.

13. Replace field and armature leads of sector scan motor.

14. Observe antenna move through sector. If hunting occurs, adjust 31-speed selsyn stator.

15. Clamp 31-speed selsyn stator.

16. Throw Scan switch to neutral position.

C. Zeroing Lobe Switch Differential Selsyn

1. Turn Power and Antenna switches on, 60 cycle off, Scan switch in neutral position, and Search switch off, 400 cycle power on.

2. Block lobe switch cam switch with paper.

3. Center lobe switch solenoid plunger and lock with wood wedge.

4. Loosen stator clamps on 31-speed lobe weitch differential selsyn.

5. Turn heading dial until antenna moves into zero reference position.

6. Throw Scan switch to Lobe position.
   Result: Antenna may move to a new heading a few degrees from this reference mark and hunt due to disalignment.

7. Adjust stator so that antenna returns to zero reference position and stops hunting.

8. Clamp selsyn stator.

9. Remove wedge from solenoid plunger and paper from cam switch.

10. Check to see that antenna moves same number of degrees on either side of zero reference mark.

11. Throw Scan switch to neutral position.

12. Turn 60 cycle switch on.

IMPORTANT NOTE

If it becomes necessary to switch channels in the servo amplifier during operation of the system, check the heading accuracy of the dials. This can be done by swinging the antenna into the zero reference position and checking the zero reading on the heading dials. The same check should be made if it is necessary to replace Model 2CV1C1 with the spare amplifier, Model 2CV1B1. The spare amplifier has a slightly different circuit but will operate satisfactorily in this system.

TROUBLE SHOOTING

Outside of typical circuit malfunctions which can be eliminated by conventional methods, there are two characteristic malfunctions which might cause some difficulty when they occur but which can be corrected using the following procedure:

HUNTING

1. Hunting begins when Power and Antenna switches are turned on.

   Cause: This is most likely caused by a disalignment between the 1-speed and 31-speed selsyn systems. In this case, each system is attempting to control the antenna which causes the antenna to oscillate between two heading positions. The indication is that the selsyns are not zeroed.
   Cure: Zero all selsyns.

2. Hunting occurs only during sector scanning.

   Cause: The 1-speed and 31-speed sector scan differential selsyns are not zeroed.
   Cure: Zero sector scan selsyns.

3. Hunting occurs only after antenna has moved through some angle.

   Cause: While this trouble might be caused by the selsyns not being zeroed, it is most likely due to some fault in the anti-hunt circuit.
   Cure: Check the anti-hunt circuit and the stabilizing condensers C3S and C4S which are located on the relay and condenser panel in the antenna servo control box. Their values are 0.25 mfd and 1.0 mfd respectively. Zero all selsyns.

CONTINUOUS ROTATION OF ANTENNA

Cause: This is caused when the servo amplifier sends out a continuous error signal only in one direction. This occurs when only one of the output tubes is conducting.
Cure: Check and replace faulty tubes in servo amplifier.

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Appendix III

POWER COMPONENTS OF ANTENNA SERVO SYSTEM

AMPLIDYNE MOTOR-GENERATOR (5AM31NJ9A)

Input (Motor)

Volts, direct current ---------------------------- 27

Amperes, direct current -------------------------- 44

Output (Generator)

Volts, direct current ---------------------------- 60

Amperes, direct current -------------------------- 8.8

Watts -- 530

Speed, rpm --------------------------------------- 8300

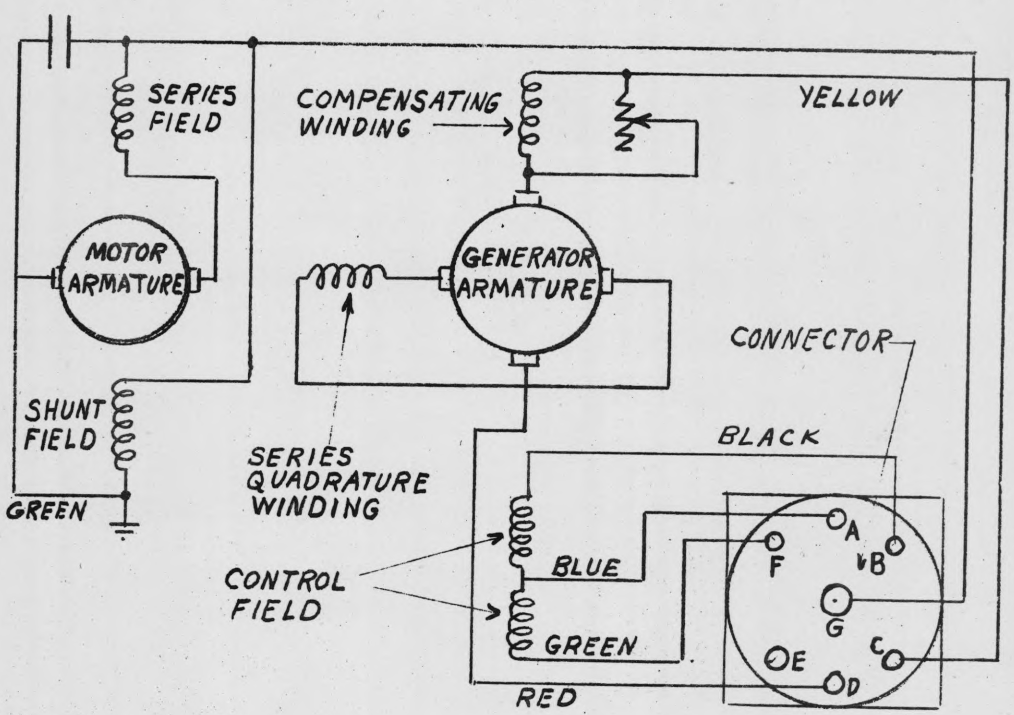

Diagram of Model 5AM31NJ9A Amplidyne

DYNAMOTOR (5D21NJ3A)

Input (Motor)

Volts, direct current	27
Amperes, direct current	35

Output (Generator)

Volts, alternating current	115
Amperes, alternating current	4.2
Phase	1
Cycles	400
Speed, rpm	8000

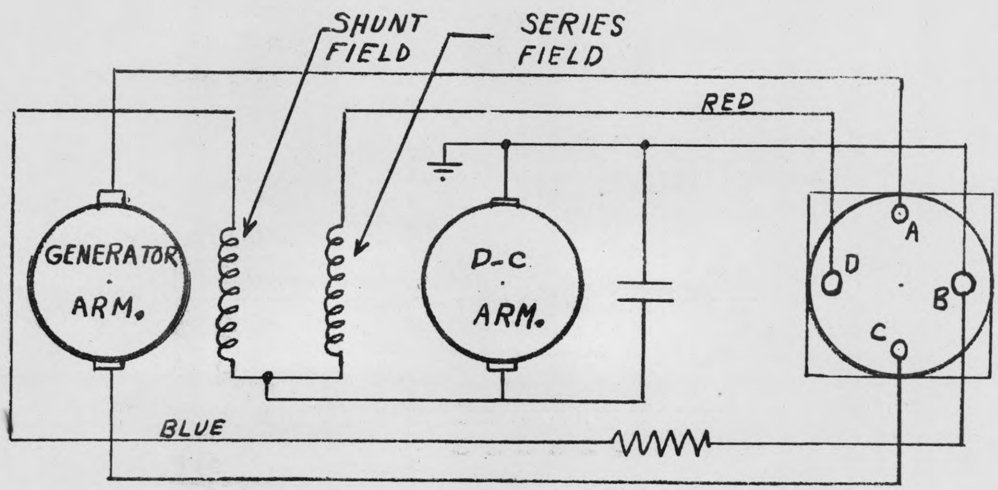

Diagram of Model 5D21NJ3A Dynamotor

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Appendix III

AZIMUTH DRIVE MOTOR (5BA50LJ2A)

Input

Stator Assembly (Field)

Volts, direct current ------------------------- 27

Amperes, direct current ----------------------- 2.3

Rotor Assembly (Armature)

Volts, direct current ------------------------- 60

Amperes, direct current ----------------------- 8.3

Output

Horsepower ------------------------------------ 0.5

Speed, rpm ------------------------------------ 4000

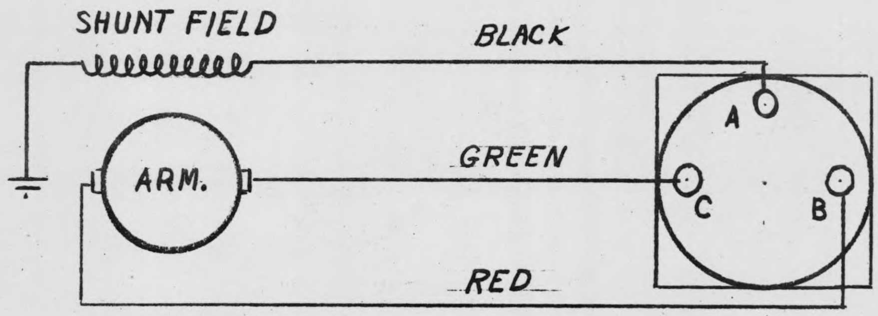

Diagram of Model 5BA50LJ2A Azimuth Drive Motor

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CHASSIS RECEPTACLES
FOR
ANTENNA SERVO CONTROL SYSTEM

JA NUMBER	LOCATION	AN NUMBER	DESCRIPTION
JA-100	Antenna Servo Control Box	AN-3102A-36-1-S	22 Pin--Female
JA-101-Orange	Antenna Servo Control Box	AN-3102A-24-20-P	11 Pin--Male c.c.--Orange
JA-102-Blue	Antenna Servo Control Box	AN-3102A-24-20-S	11 Pin--Female c.c.--Blue
JA-103-Red	Antenna Servo Control Box	AN-3102A-24-20-S	11 Pin--Female c.c.--Red
JA-104-Yellow	Antenna Servo Control Box	AN-3102A-24-20-S	11 Pin--Female c.c.--Yellow
JA-105	Antenna Servo Control Box	AN-3102A-24-22-P	4 Pin--Male
JA-106	Servo Amplifier	AN-3102A-28-17-P	15 Pin--Male
JA-107	Antenna Junction Box	AN-3102A-28-11-S	22 Pin--Female
JA-108	TS-34 Scope	AN-3100A-12S-3S	2 Pin--Female
JA-109	Plotting Table	Jones (300)	10 Pin--Male
JA-110	Plotting Table	Jones (300)	4 Pin--Male
JA-111	Power Distribution Box	Jones (400)	4 Pin--Female 400 cycle outlet
JA-112-Red	Power Distribution Box	Jones (400)	6 Pin--Female c.c.--Red
JA-113-Yellow	Power Distribution Box	Jones (400)	6 Pin--Female c.c.--Yellow

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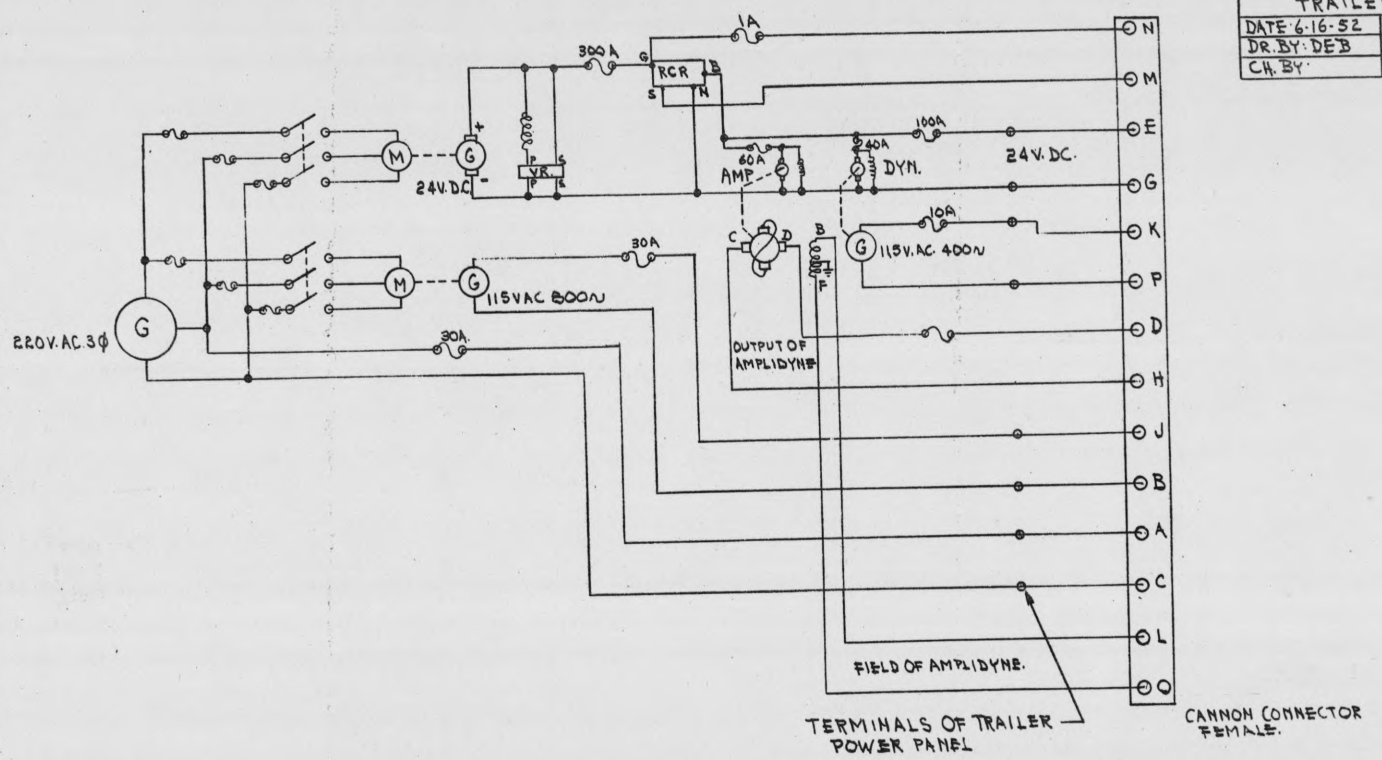

UNIVERSITY OF ILLINOIS CONTROL SYSTEMS LAB.	
WIRING DIAGRAM OF TRAILER POWER UNIT	
DATE 6-16-52	SCALE NONE
DR. BY: DEB	NO. B-4028.
CH. BY:	

33-59/64

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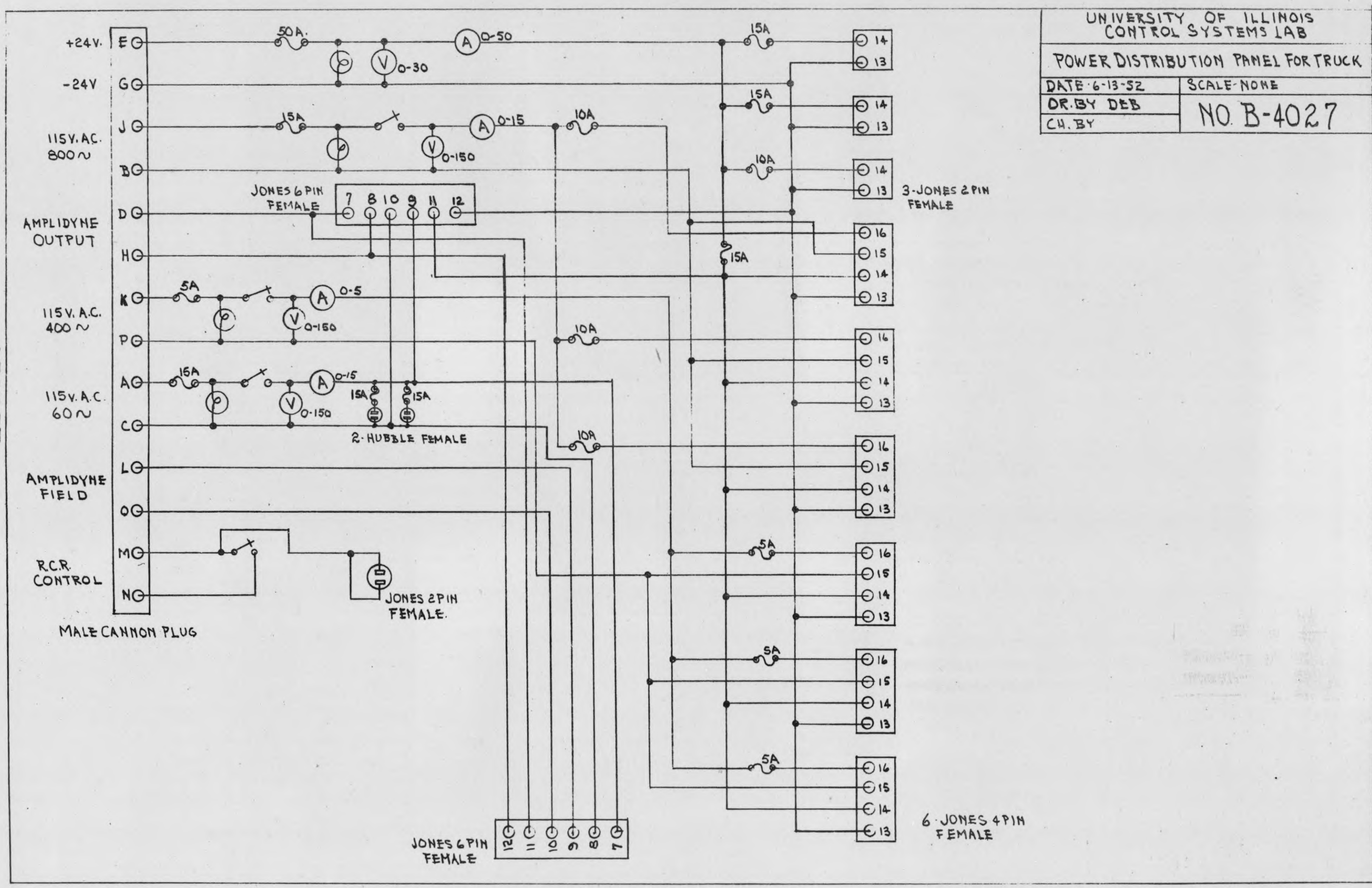
SECRET



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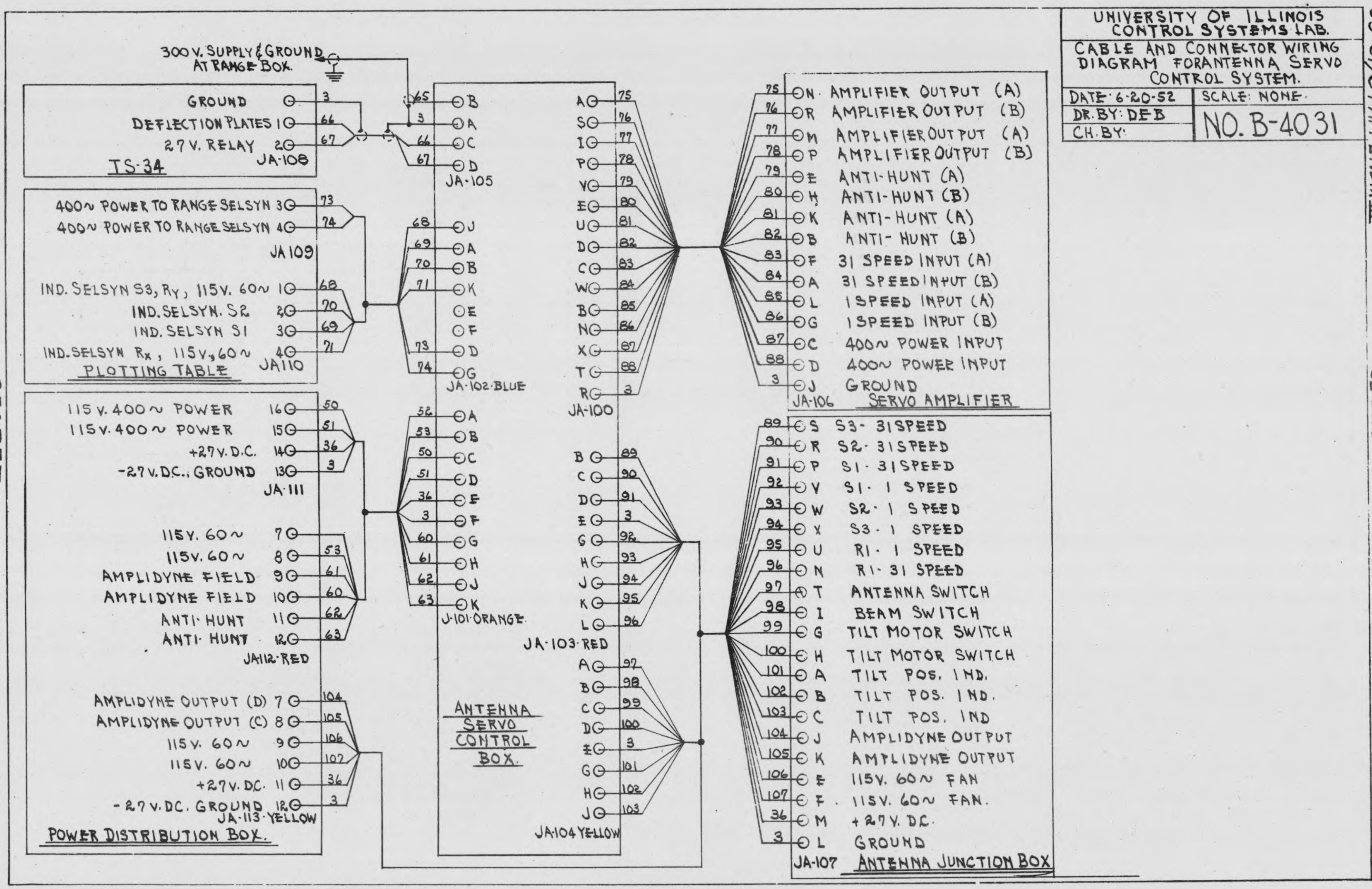
APPENDIX III

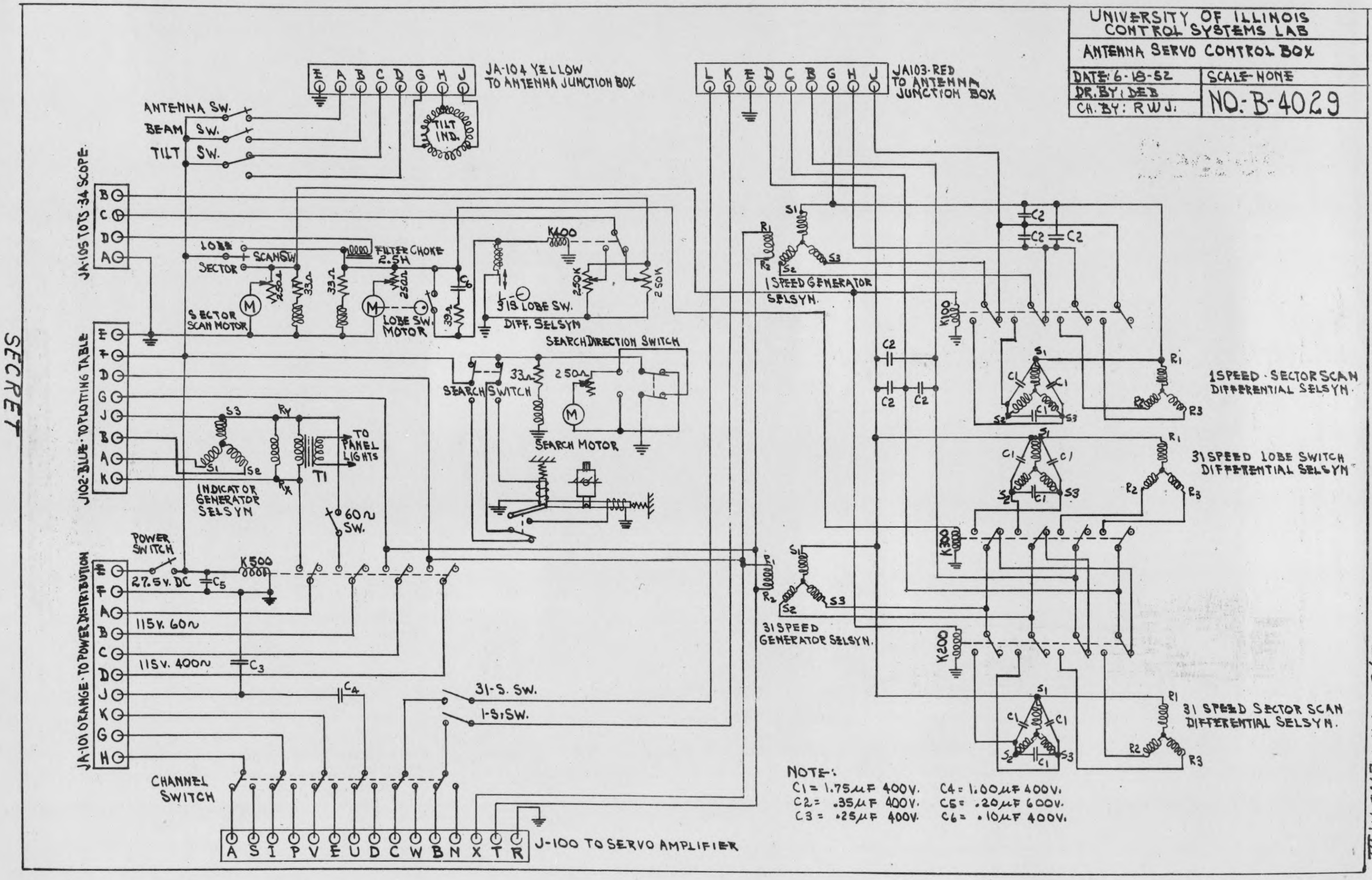
33-61/64 APPENDIX III

SECRET



SECRET

SECRET



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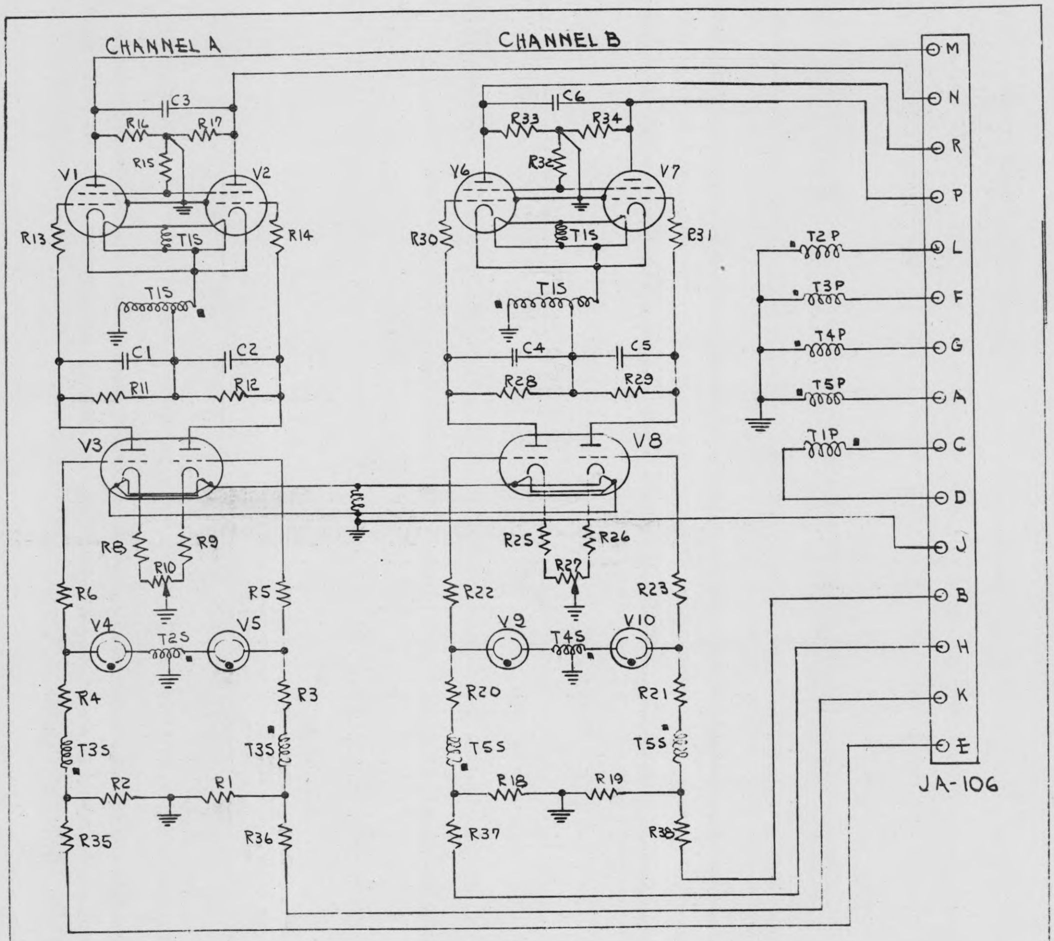
33-63/64
APPENDIX III



DESCRIPTION.

TUBE NO.	TYPE	
V1, V2, V6, V7	6L6	
V3, V8.	6SN7GT	
V4, V5, V9, V10	CD-2005 (NEON)	
RESISTORS.	**OHMS**	**WATTS.**
R1, R2, R18, R19	75,000	½
R3, R4, R5, R6.	500,000	½
R20, R21, R22, R23	500,000	½
R8, R9, R25. R26	3,000	½
R10, R27,	500	IRC TYPEW POT
R11, R12, R28, R29	75,000	1
R13, R14, R30. R31	100,000	½
R15, R32	10,000	2
R16, R17, R33, R34	5,000	8
R35, R36, R37, R38.	25,000	½
CAPACITORS	**MICROFARADS**	**VOLTS**
C1-C2, C4-C5	.1-.1	500
C3-C6	.05	500

TRANSFORMERS

T1	400~ POWER TRANSFORMER
T2, T4	1 SPEED TRANSFORMERS
T3, T5	31 SPEED TRANSFORMERS

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CONTROL SYSTEMS LAB
WIRING DIAGRAM FOR
MODEL 2CV1B1
SERVOAMPLIFIER.

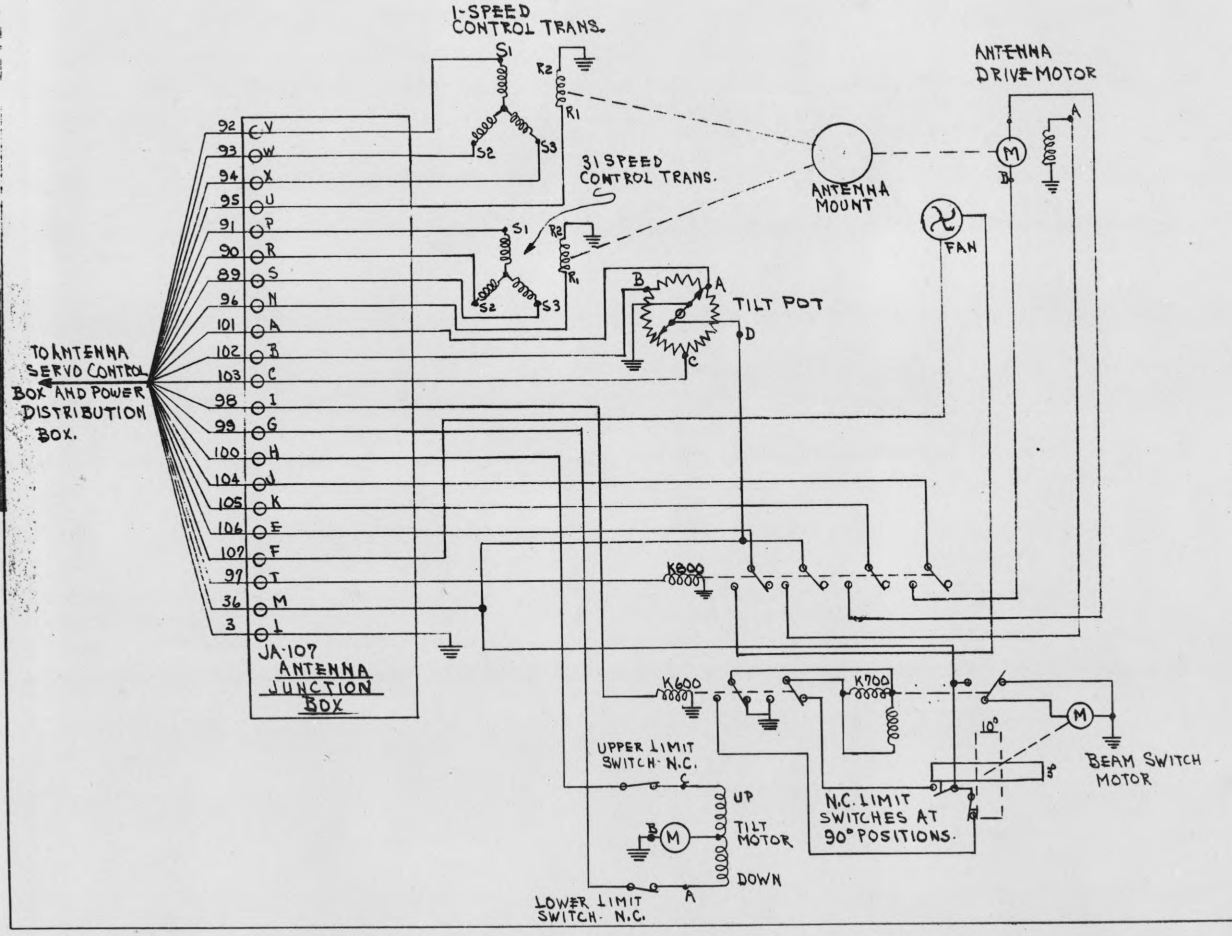
DATE 6-30-52	SCALE-NONE
DR. BY: DEB	NO. B-4039
CH. BY: RWJ	

[redacted]

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~ [redacted]

UNIVERSITY OF ILLINOIS CONTROL SYSTEMS LAB	
ANTENNA WIRING DIAGRAM	
DATE 6-20-52	SCALE · NONE
DR BY: D.E.B.	NO. B-4032
CH. BY:	



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33-64/64 APPENDIX III

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